BIOLOGY

THE WORLD OF LIVING THINGS

AN INTRODUCTION TO THE STUDY OF PLANTS AND ANIMALS; THE GROWTH, BEHAVIOUR, COURTSHIP AND REPRODUCTION OF LIVING THINGS; THE BODY AND MIND OF MAN; AND EVOLUTION AND HEREDITY

CONTRIBUTORS

H. R. Hewer, M.Sc., A.R.C.S., D.I.C.
F. Martin Duncan, F.R.M.S., F.R.P.S.
V. H. Mottram, M.A. (Cantab.)
Norman Prichard, M.Sc. (London)
Professor H. P. Gilding, M.A., M.D.
E. L. Grant Watson, B.A. (Cantab.)
L. R. Brightwell, F.Z.S.
H. Mortimer Batten
Seton Gordon, C.B.E.
E. G. Boulenger, F.Z.S.
A. J. Cain, M.A. (Oxon.)
C. B. Williams, M.A., Sc.D.
Professor F. A. E. Crew, F.R.S., M.D., D.Sc., Ph.D.

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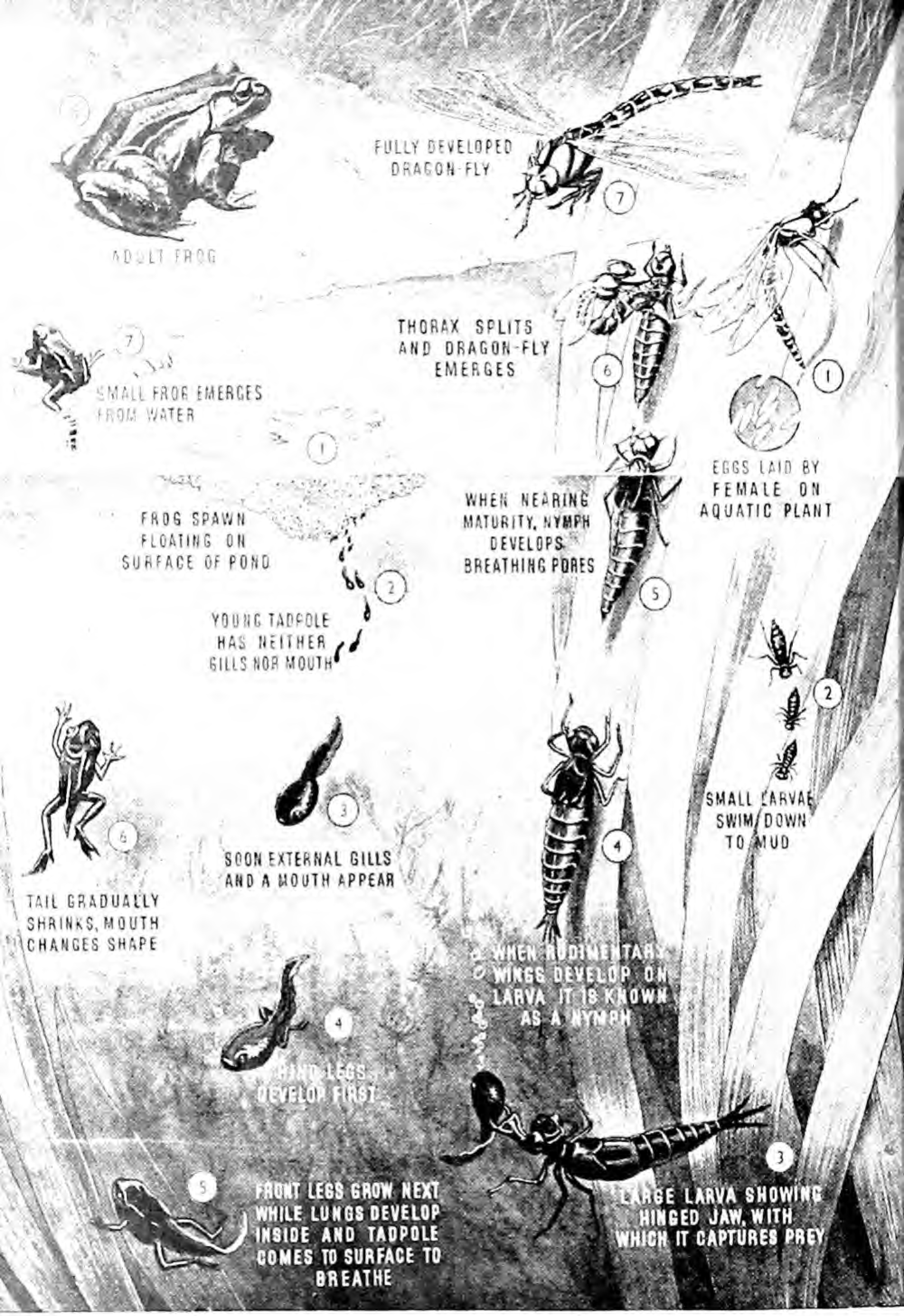

LIFE HISTORY OF FROG AND DRAGON-FLY

The stages of development of a frog from spawn to adult animal are shown on the left. The right-hand half of the picture depicts similar stages in a dragon-fly's life.

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CONTENTS

CONTENTS

LIFE IN THE HEART OF THE JUNGLE

In the dense jungles of tropical lands, where man seldom sets his foot, life flourishes abundantly. Strange plants compete with each other to reach the sunlight, and large carnivorous beasts like the tiger are the lords of creation.

CHAPTER I

LIVING AND NON-LIVING THINGS

BROADLY speaking, everyone knows what is meant by living things, but when we come to define life accurately, as we must do if we are to study it with any effect, we come up against difficulties. These are of two kinds; one is that there are borderline cases complicating simple definition and the other is that words, particularly common and much used ones, do not always mean the same thing to different people, or carry shades of meaning in varying conditions.

For example, we may say that it is characteristic of living organisms that they grow. But crystals grow in saturated solutions. In the first statement we mean that growth in the biological sense takes place—and it may take us quite a long time to explain what that involves.

In the second, we can substitute the word increase without altering the meaning, and this implies no enlargement in the biological sense.

Despite these difficulties, which are due in part to the incompleteness of our knowledge and in part to the deficiencies of language, there are real distinctions between living and non-living things. We will try to define these as briefly as possible first of all and then clarify the short statements, partly by statements of what they do not mean and partly, in the rest of this book, by the study of living organisms themselves.

Before giving these definitions, we should make it clear that we are really beginning at the wrong end. These definitions are not something that biologists started with; they are the result of study over generations and centuries. Even now, they cannot be considered final, but are subject to revision if fresh facts come to light which suggest that the definitions are not quite adequate.

It is one of the dangers of learning a science that this can be done so much more easily if a framework of general definitions and conclusions is presented at first, so that, as the student proceeds to study and learn the great body of details comprising the science he can have something to hang on to.

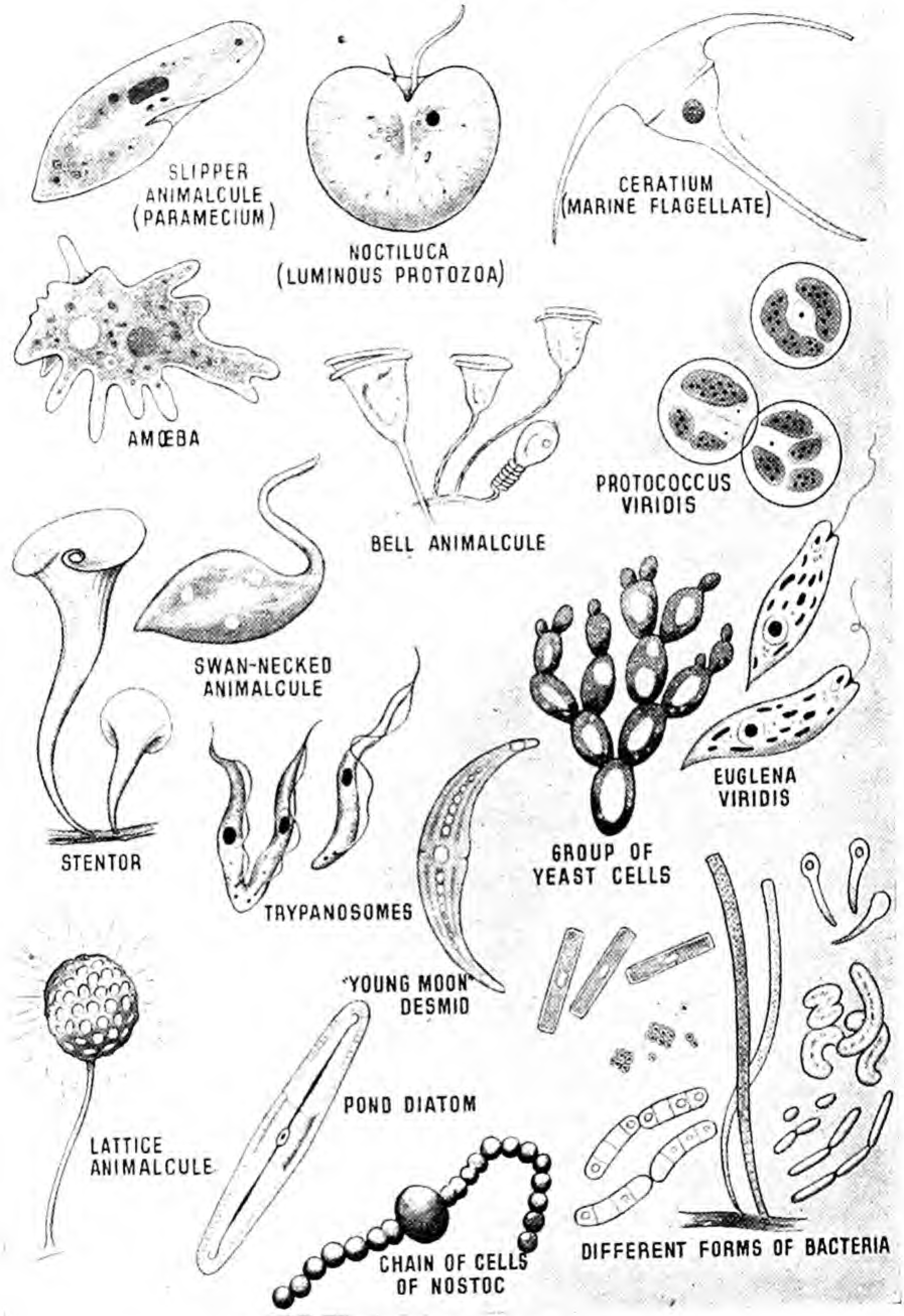
Later, when he begins to collect facts for himself, although he will inevitably relate them to the general framework, he must never forget that these new facts may not fit the framework but that the truth of the framework must be tested again and again by its ability to accommodate the facts. This is the scientific method: the acceptance for the time being as though they were true, of generalizations which suggest and permit new facts to be discovered, and the continual testing of the generalizations and conclusions by the new facts as they come to light.

Fundamental Difference

So far as we know now, then, living things are distinguished from non-living things by possessing certain properties unknown in the dead world. First and foremost, living organisms are able to take matter different both chemically and physically from themselves and to incorporate it in a changed form into their bodies. This is the fundamental difference from which all the others derive. These other differences may be generally referred to as activities.

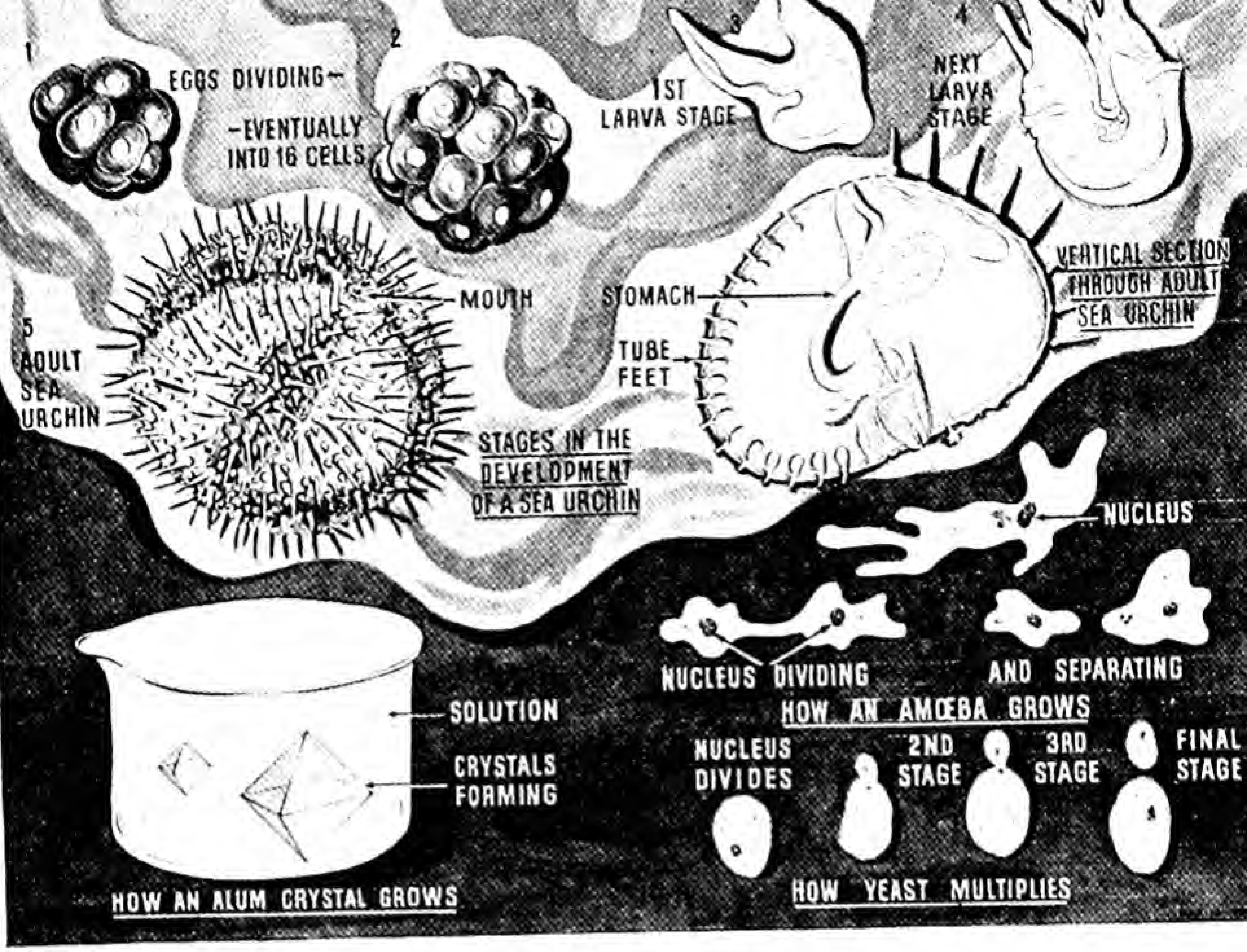
Living organisms may move, feed, breathe, reproduce, etc., but none of these is possible unless they can obtain material and energy from external sources and turn them to their own use. We shall see shortly that the way they do so enables us to draw a fairly clear line between animals and plants. Before going more deeply into this fundamental activity of living organisms, let us see what the other activities comprise.

The obtaining of material which becomes assimilated into the organism's body results in growth. In its widest sense, generally considered under the term development, it may mean an increase in the com-



ELEMENTARY FORMS OF LIFE

Some unicellular forms of life in the animal and the plant worlds; most of them live in water. Some exist independently, while others unite to form groups or colonies.



INCREASE AND GROWTH

Although alum crystals will increase in solution, the gradual development of a sea-urchin from the single egg-cell represents growth in the true biological sense. Amoeba grows until it is ready to divide into two and start all over again. Yeast develops a small swelling, or bud, which eventually becomes detached from the parent cell and forms a new individual.

plexity of the organism, or it may entail simply an increase in the size of the organism as a whole or of one or more of its parts.

The material used for growth is the surplus left over after replacement of matter used up in the normal activities of the animal or plant. When the supply of material does no more than replace normal wastage, growth ceases; if it does not do even that, senility sets in and will ultimately end in death.

Another outlet for assimilated material is in reproduction. This may be described as the mechanism by which the dynamic systems known as organisms perpetuate themselves.

A chemical substance, such as fluorspar or silica, may be found in rocks and if not unduly subjected to chemical action by the weather remains as such. Common salt is common salt the world over; it may become dissolved, but can be recrystallized again. An organism cannot thus stand still; it is either growing or in some stage of senility towards death. The continued persistence of a kind of organism, therefore, depends upon its power of reproduction.

In the pursuit of material upon which the organism is to feed and drink or breathe, a number of subsidiary activities are necessary. Unless the source of food supply is all around the organism (as air is for human beings, water for fish, salts and water for the roots of plants), the organism must move. Movement, then, is one of the characteristics of most animals and this entails coming into contact with many features of the environment. Sensitivity has, therefore, been developed, together with excitability, to enable animals and, to a lesser extent plants, to react successfully to their environment.

Activity of all sorts implies chemical and physical changes in the materials of which organisms are composed, and a further series of activities is distinguished covering

SEA-ANEMONE AND ITS PREY

Sea-anemones cannot move quickly in search of food so must take what comes along. They have mouths surrounded by stinging tentacles with which they seize any little creature passing by. The tentacles curve inwards and draw the victim into the mouth.

these fields. We have already mentioned assimilation and more will be said about this in Chapter V and about its counterpart, photosynthesis, in plants. Respiration is generally taken to define the gaseous exchanges between organisms and their surrounding atmosphere, based on oxygen and carbon dioxide interchange. Excretion consists of the removal of waste materials from the organism.

Waste materials are those which in one form or another have served their purpose in the organism and whose continued presence is no longer necessary or even desirable. Between this and secretion there is a very narrow barrier, some secretions having been evolved from excretions. Thus, some substances are taken in by the organism, absorbed or assimilated and finally disposed of, as of no further use in living tissues, in dead material which, like hair, is still attached to the organism and forms a covering which is used in regulating body temperatures.

We have now seen the essentially dynamic character of living things and how this is manifested in a series of activities, the details of which will be considered later in the book, when it will become increasingly clear that these activities cannot be paralleled in non-living things, even though there may be superficial or verbal resemblances at times.

Two Great Divisions

Within the living world there are popularly two major divisions, the animal and the plant. This is a very real distinction but, like all distinctions concerning things of very varied range, liable to become obscure at one end or other of the range. Thus, we find great difficulty in deciding whether many of the little organized forms of life (we call them lower forms because we like to flatter ourselves as being at the higher end) are animals or plants.

The fact of the matter probably is that they are neither, because they have never evolved past the dividing point; the choice, to speak humanly, has never been given them. To this group belong the viruses, the spirochætes, the bacteria, some kinds of

algæ and many of the protozoa. By common consent the first four are dealt with by botanists and the last by zoologists, but there is much overlapping.

The definitions of animals and plants are subject to the same reservations as those of living organisms (see page 7). Within the range of each, there are such wide variations that only a few features can be truly said to be common to either animals or plants.

If you take and examine the plants in your gardens you would probably say that they are generally greenish in colour, have leaves, stalks and roots, flower at some season of the year and bear seeds or fruits afterwards. Which of these things is applicable to the ferns or to the seaweeds of the seashore, or to the *fungi* and *moulds*?

Now take a look at some animals; yourself, your dog or cat, birds, frogs, insects, spiders, snails and slugs, worms, sea-anemones and sponges! Where can be found common characteristics? Typically enough they are not to be found in what they are or have (in their appearance), but in what and how they do things (how they behave or act).

At first sight we might be content by saying that plants are fixed and do not move of their own will, while animals are free to move about. But what about sea-anemones and sponges? Well, sea-anemones do just move! An inch or two at a time, and very slowly, but their close relatives, the corals, do not move at all, nor do sponges when once the young stage (or larva) has settled down on a rock or stone.

No, we must go further back and find the reason why nearly all animals move and plants do not move. This reason we find in the way in which animals and plants obtain their food and the sort of food that is used by them.

Animals live on complex organic matter as well as on air, salts and water. They take these organic compounds in the form of living or dead matter such as grass, leaves or meat, break them down inside themselves to simpler compounds and assimilate them, building them up again to their purposes.

Plants, on the other hand, take the simple gases, water and salts from the air and soil, and, by means of the green chlorophyll they possess, use the energy of sunlight to synthesize or build up the organic compounds of which they are composed.

To this, as to most definitions, there are

MARSH MARIGOLD

Like all green plants, it loves the sun, for sunlight is essential for the formation of chlorophyll and for the process of photosynthesis.

apparent exceptions. Fungi, for example, do not have chlorophyll and derive their nourishment in a different way altogether. However, botanists are agreed that they are true plants because they possess several features, such as their means of reproduction, which are plant-like.

Living Matter

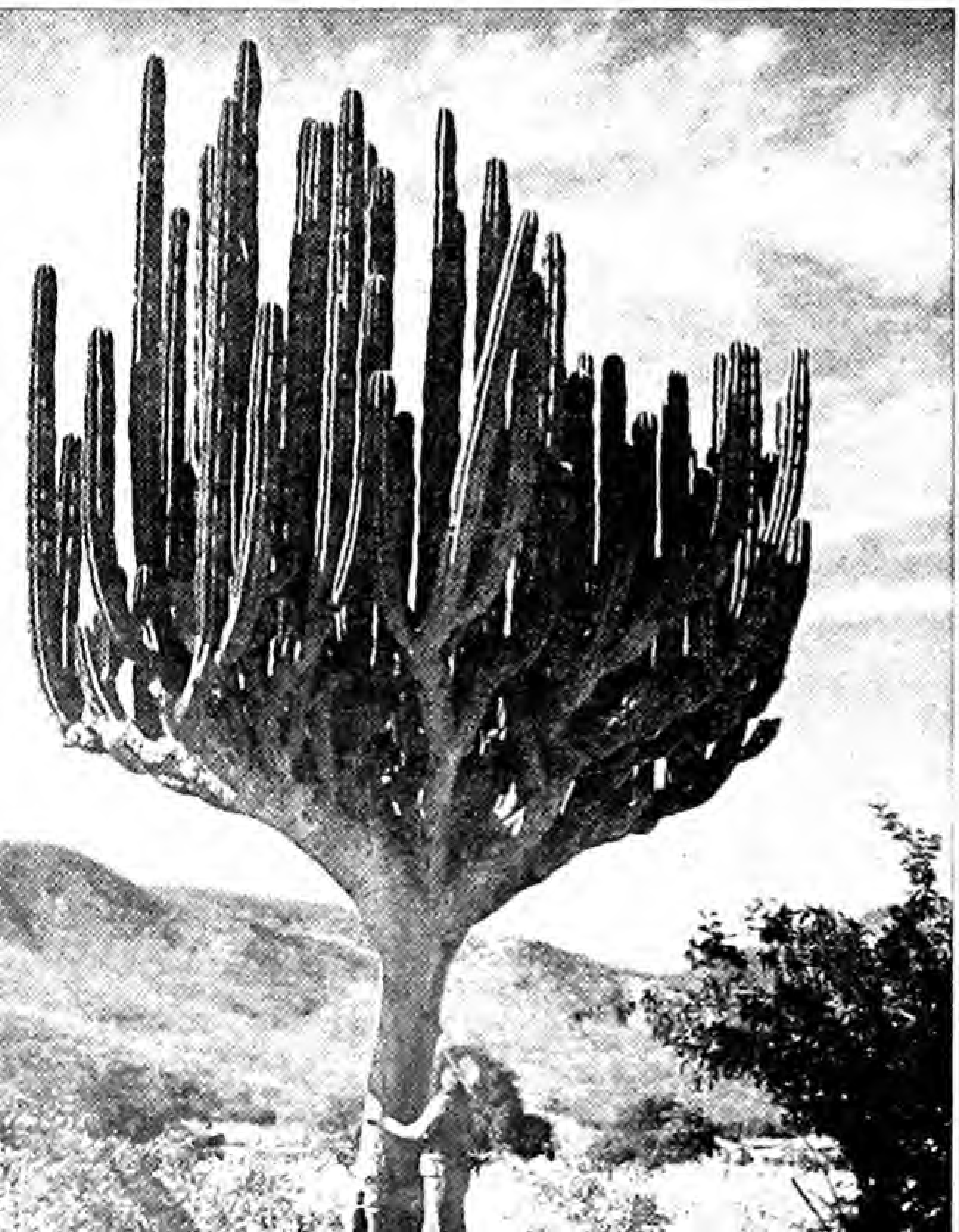
All living organisms are composed of matter to which the name protoplasm has been given. It is really this protoplasm which possesses those powers of reaction which we have described as typical of living organisms. Protoplasm itself is a complex system of organic compounds, water and salts capable of almost infinite variation in detail but having very definite physical and chemical properties. Essentially it is an emulsion, that is, a mixture of suspended particles of various compositions and sizes, in a more fluid medium.

A simple emulsion can be made by shaking together oil and water. The more it is shaken, the more fine globules of oil will be found and these will remain suspended for some time in the water. Eventually, however, they rise and the two components appear as two layers of oil and water. Such an emulsion is not permanent and is unstable. Protoplasm is a permanent emulsion, physically stable, because the chemicals of which it is composed are colloids which possess physical properties enabling them to form permanent emulsions.

We cannot go into the chemistry and physics of colloids here, and it is sufficient for us to know that colloidal emulsions form extremely intimate systems of chemical substances and are capable of great variation and delicate adjustment; just the sort of material background for the evolution of living organisms.

Protoplasm may contain within itself, as it were, dead material as a result of its activities. Globules of fat may be formed and act as a store of food which can later be drawn on if necessary. In plants, starch grains are the commonest form of storage particle. Such instances can be multiplied many times. Protoplasm may also form dead material around itself. Parts of cartilage and bone are examples in animals; cellulose and woody fibre in plants.

While the production of such materials is very characteristic of protoplasm, these materials are not part of the protoplasm and must be considered as matter which is, at least temporarily, outside the



THE ROOTED PLANT

The inability to move about is a distinguishing characteristic of plants. The solid looking cactus is scarcely even stirred by the wind.

FREE, VIGOROUS ANIMAL LIFE

The horse was one of the first animals to be domesticated and wild horses (as above) that scour the plains of Arizona today are probably descendants of domesticated animals that have reverted to a wild state. Long before the dawn of man, however, ancestors of the horse trod the earth, for its descent has been traced back from fossil evidence, through the ages, to a small four-toed animal that existed over forty million years ago.

sphere of living matter although their presence is essential to the working of the living organism as a whole.

Even in the most lowly forms of life, some degree of organization is found in protoplasm. This may be only in the presence of a surface membrane determining the shape of the organism, as in bacteria. In slightly higher forms we can distinguish a body (or bodies), called the nucleus (or nuclei). This is so important that something more must be said about it.

Function of the Nucleus

The nucleus itself is surrounded by a membrane and contains well defined particles called chromosomes because they stain very readily in certain dyes (Greek, *chroma*=colour). These chromosomes are now known to be extremely important in the reproduction and development of the organism, controlling, even if only remotely, the whole organism. The nucleus is, therefore, a sort of control centre for the surrounding protoplasm, which is known as the cytoplasm.

The amount of cytoplasm which can be controlled by a single nucleus varies considerably, but it is possible that there is a limit set by some factor we do not yet know about. At any rate, above a very limited size of protoplasm one of two things takes place. Either the nucleus divides and becomes two, separating each to its own sphere of activity, or this happens first and is then followed by a division or separation of the cytoplasm as well.

Cells and Organisms

These units of nucleus and cytoplasm are called cells, and organisms not divided into them are called non-cellular; the others, comprising the vast majority of forms, are cellular. At one time, it was thought all organisms were cellular and the non-cellular ones were called single-celled. This theory implied that the multicellular organisms could be considered as collections of single cells rather than a single organism sub-divided into cells.

We now know this latter view to be the more correct one and regard the organism as the unit of living things and not the cell. Nevertheless, for study purposes we often have to regard the cell as a unit, but always remember that it is part only of the real unit, the organism.

When organisms are cellular in structure, further opportunities occur for complexity of organization. Groups of cells become specialized to perform certain functions only, such as digestion, contraction, conduction of nervous impulses or supporting framework. They take on special characters and come to form a recognizable unit called a tissue.

Thus we get muscular tissues, nervous tissues, connective tissues and so on. In becoming specialized, most cells lose the power of performing other functions, so that the advantage of having just the right kind of cell for each job is offset by an inability to take over jobs should injury occur.

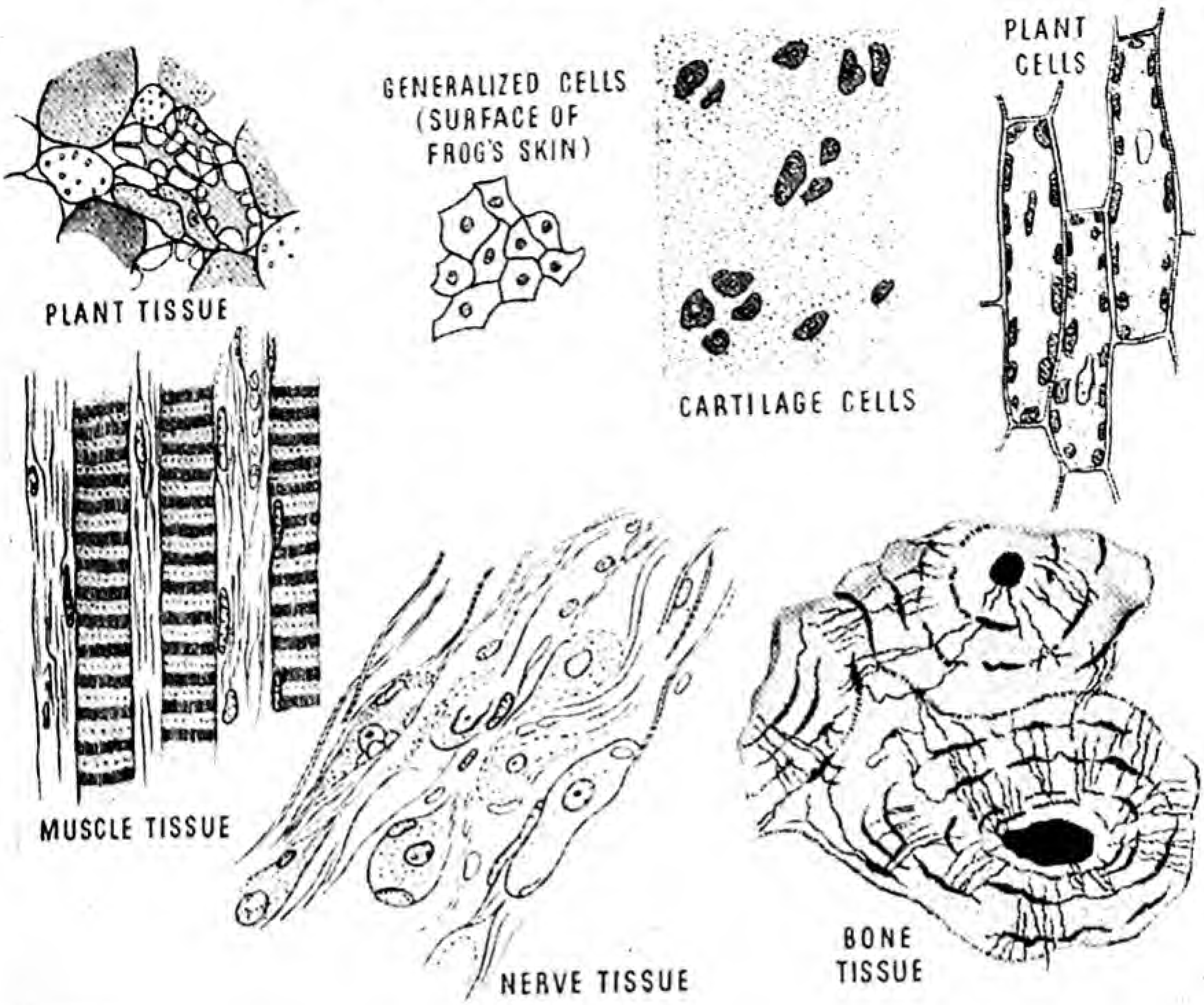
The advantage usually far outweighs the disadvantage in practice because there is always a reserve of less specialized cells which give rise to replacing cells of probably more than one kind of tissue.

Association of Tissues

Generally speaking, and except in special places, it is rare to find only one kind of tissue *en masse*. Even in comparatively pure tissues, like muscle or nerve, there are connective tissue cells which bind the others together. The association of several kinds of specialized cells (tissues) together forms an organ.

Each component tissue is essential to the full and proper working of the organ. Thus the stomach of a mammal comprises a lining tissue (epithelium), several glandular tissues (to secrete the digestive juices), muscular tissue (to assist the movement of the food), blood (to nourish all the other tissues), nerves (to control all the various activities) and, finally, connective tissues binding all together into a compact organ.

Again, the arm of a man comprises a covering tissue (epithelium), glandular tissues (producing sweat as part of the temperature-regulating mechanism), a great deal of muscular tissue arranged in bundles attached by tendons (fibrous tissue) to the bones (skeletal tissue), all being supplied



CELLS AND TISSUES

Cells are minute units composed of protoplasm and consist of two parts, the nucleus, or control centre, and the cytoplasm which surrounds it. Tissues are groups of similar cells which have become specialized or adapted to perform specific functions.

with blood and nerves and held together with connective tissues.

Sometimes, of course, it is difficult to decide whether we are dealing with an organ or a region of the organism. Usually, the name region is given to a larger mass of the organism, but the principle is the same: the association of tissues, or even organs, into a larger unit to serve a more complicated or comprehensive function.

Finally, we have the organism itself as a summation of all its parts performing the function of living. It is generally agreed that this building up of specialized parts into a unified whole results in something more than a mere answer to an addition sum.

An organ cannot function by itself, but only as a part of the whole, each part deriving something from the other yet remaining itself intact. Thus the whole organism must be regarded as something greater than a sum of its parts. This is what we mean to emphasize when we say that a living organism itself and not the cell is the real unit, and that the reactions of parts of an organism can be properly interpreted only when considered in conjunction with the rest of the organism. We are, however, getting into the realm of metaphysics, which although important to the research workers does not require to be elaborated here.

Before leaving the subject of organization of the body of living organisms, it is desirable to explain the reasons for some of the confusing names which are used by the specialist. At the outset, let it be said

that the names used by the amateur, or layman, are equally confusing. Let us take two examples one on each side, both from the same two animals, a crayfish or lobster, and man.

The specialist will tell you that the food passes from the mouth down a short tube to the proventriculus.

"What on earth is that?" says the layman.

"Oh, it's a sort of stomach," says the specialist.

"Well, why not call it stomach instead of that jaw-cracking name!" says the layman.

"Because if I did," replies the specialist, "it would give you the wrong idea altogether.

" The crayfish does quite a lot of chewing of its food in the proventriculus, even though it is the first and only large bag-like swelling in its gut. Besides, it is developed and has been evolved in quite a different way from the stomach of man or a mammal."

"All right," says the layman sadly, "if it is different let us call it by something different. I suppose you don't mind saying that the crayfish has a pair of eyes?"

"No," says the specialist, "not absolutely; I should prefer to call them compound eyes to indicate that they are quite different from your own eyes, which have only one lens and a single large retina."

"Oh!" says the layman, "they are really just as different as the two stomachs then?"

"Certainly they are," replies the specialist, "but we can add the word compound easily and, after all, they do serve the same function. Of course, there is another sort of eye thing which is quite different again, which we call an ocellus. It is so small that you laymen haven't seen it to give it a wrong name!"

That, then, is the position, either to use a common and well-known name in a new and wrong sense or to use a new name, difficult perhaps to learn, for a new organ or structure. As the specialist must be precise, he usually chooses the latter, while the layman is at liberty to use the more common name, but he must remember the new sense in which it is used if he wishes to avoid falling into serious error.

We have seen that the characteristic features of animals lie in their way of living. We must now elaborate these a little before going into details. The fundamental activity is the method of feeding. This has been stated in general terms as the taking in of complex organic matter, breaking it down into simpler components and then building these up again into further and different complex compounds suitable to the animal. The series of activities thus comprised in feeding are:

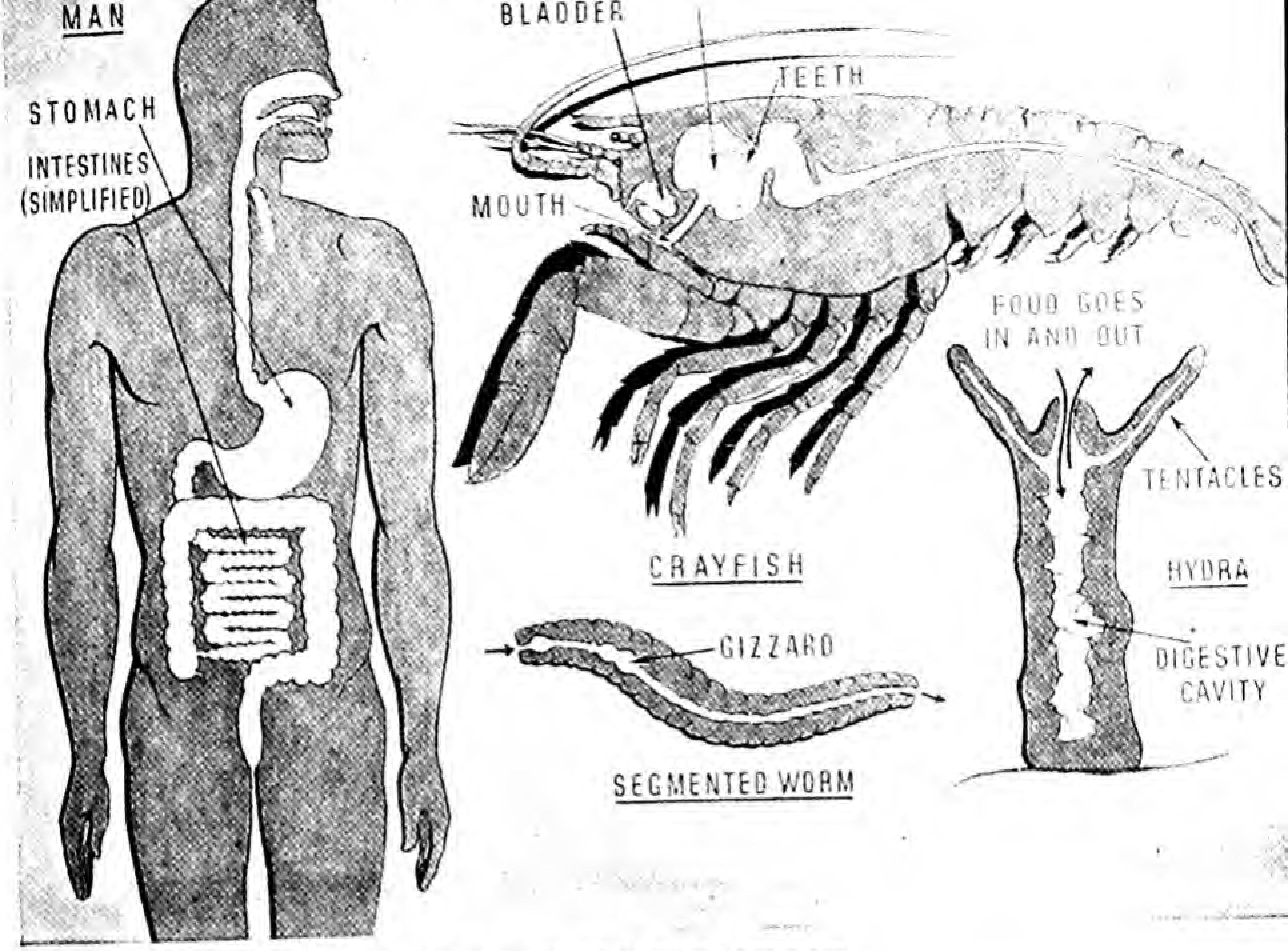
(1) ingestion, or the taking of food into the body;
(2) digestion, or the breaking down of food to a soluble form;
(3) absorption, or the passage of the now soluble food materials into the substance of the animal body;
(4) assimilation, or the use of the food materials either as immediately required energy or for building up new living substances in the body;
(5) egestion or defecation is the elimination from the body of those parts of the food which are not digested and, consequently, can never be absorbed or assimilated. Therefore this is an activity resulting from 1, 2 and 3 above and not from 4.

We must now face squarely the fact that the structure of an animal has been evolved to perform the function of living and that the individual parts, in so far as they can be separately studied, have similarly been evolved to perform the separate activities which make up the act of living. Fundamental functions are, therefore, performed by fundamental structures or organs.

Alimentary Canal System

The presence of organs, collectively forming a system, to perform the series of activities detailed above, is fundamental in animals. This system is called the alimentary canal and consists, basically, of a cavity in which the food can be contained while the processes of digestion and absorption are carried on. These activities must take some time and, therefore, the food must be retained to allow them to be fully performed.

It naturally follows that in the evolution of this cavity there will have to be evolved



STOMACH AND PROVENTRICULUS

A hydra possesses a very rudimentary form of stomach. The earthworm's digestive system is more complicated but it has no stomach; a long intestine extends nearly the whole length of the body. Man chews his food in his mouth and digests it in his stomach, but the crayfish combines both these operations in the proventriculus.

along with it an entrance or mouth. Animals must have a special place through which the food can find its way into the body. As we survey the animal kingdom, we notice that in the course of evolution the alimentary canal has become specialized. Another opening, called the anus, has been formed to allow egestion to take place elsewhere than through the mouth. This permits the development of structural specialization of the cavity and its walls along a line from mouth to anus, so that feeding can be a continual process and the animal does not have to wait for complete digestion, absorption and egestion before taking in another meal. A study of these specializations will be made in subsequent chapters.

There are two other activities which may be described as supply activities: the obtaining of water and of oxygen. To get a clear idea of these in their original form we must forget about animals living on land, that is, in air, and consider the more primitive ones living in water (aquatic animals). These are surrounded in both requirements since natural water contains much dissolved oxygen.

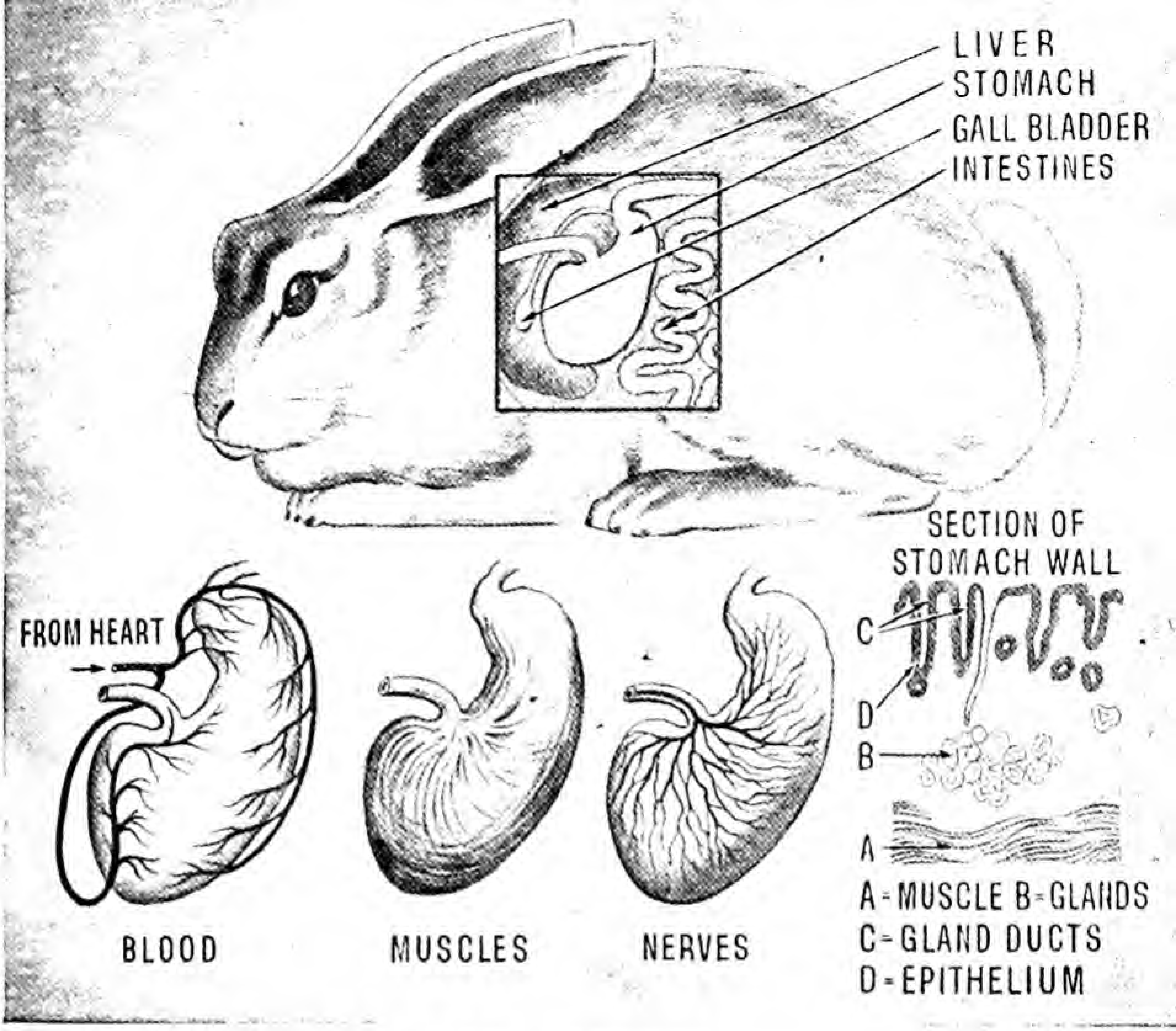
Primitively, therefore, we do not find special parts of the animal body capable of obtaining water or oxygen; both can be absorbed almost anywhere on their surface. From this point we find that many aquatic animals have increased their efficiency for obtaining oxygen by having special organs over which a current of water is passed, so that more oxygen is available than would be the case if the animal was dependent solely on the water which came into contact with its skin.

When we turn to animals living on land we find a rather different picture. In the first place, water must be taken in specially. Of course, a good deal comes in with the food and some animals have adjusted themselves so that this is all they want. Others have to drink, using the existing alimentary canal as the special organ.

To obtain oxygen from air is no more difficult than to obtain it from water, but

REINDEER SLAKES ITS THIRST

Water is one of the necessities of life and no organism can exist for long without it. It is continually being lost through evaporation or excretion and must be replaced. The reindeer is a large species of deer found in northern regions. Reindeer are characterized by their magnificent antlers and by the fact that these are borne by both sexes, although those of the male are larger and more complex. The horns are shed at the beginning of winter.



RABBIT AND ITS STOMACH

The stomach is organized to play an important part in an animal's alimentary canal system. In a mammal, such as the rabbit, the stomach is composed of various kinds of tissue, blood and nerves bound together with connective tissue to form an organ.

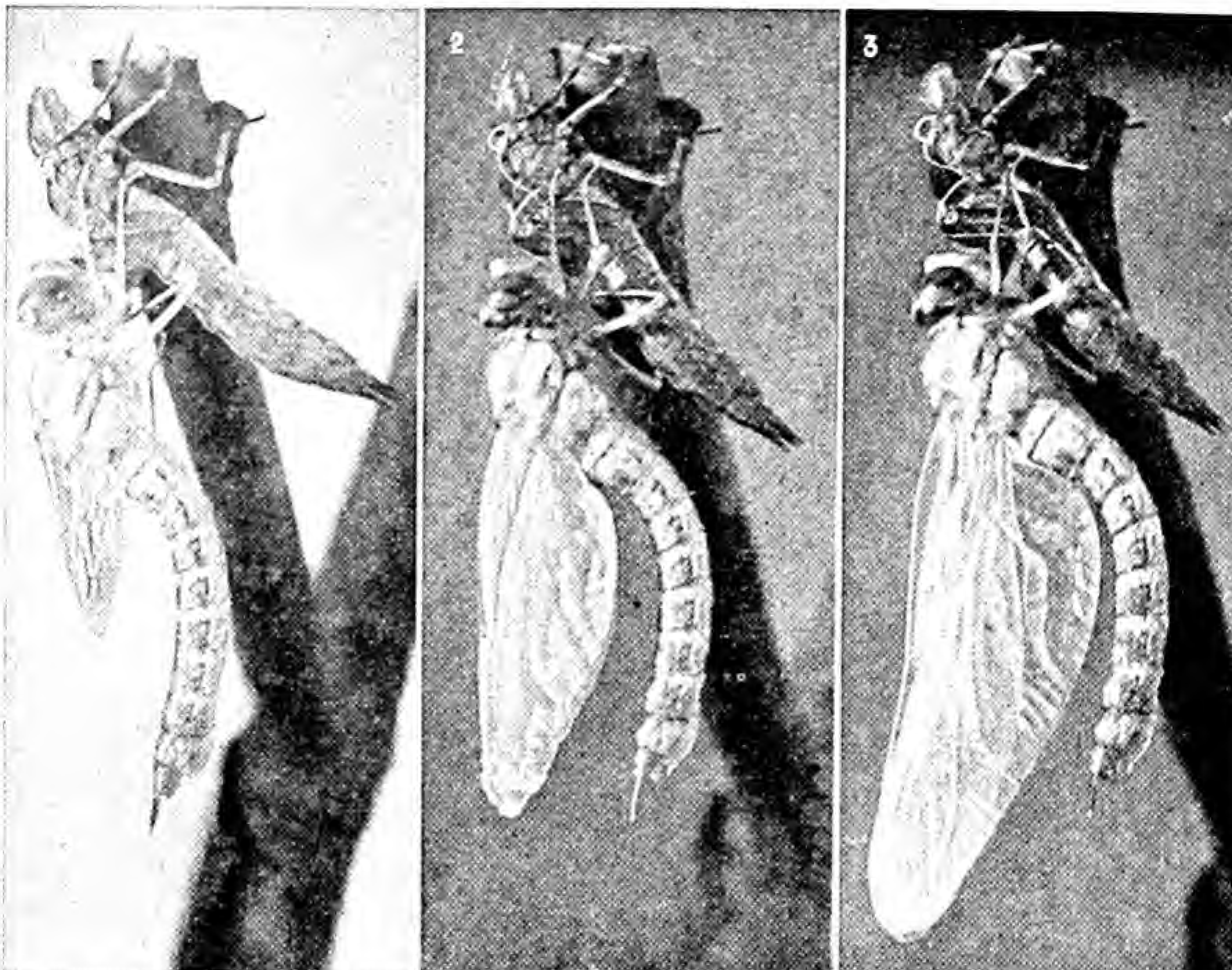
there arises a secondary problem which has determined the form the breathing organs shall take. Oxygen can only be absorbed in solution into the body substance, so that at some point or other the air must come into contact with a moist surface of the animal. Now this moist surface is wetter than the air and there will, therefore, be a loss of water from the animal into the air. This can, of course, be easily seen in cold weather when our breath, warm and moisture-laden, condenses in the drier and colder air outside to form a mist.

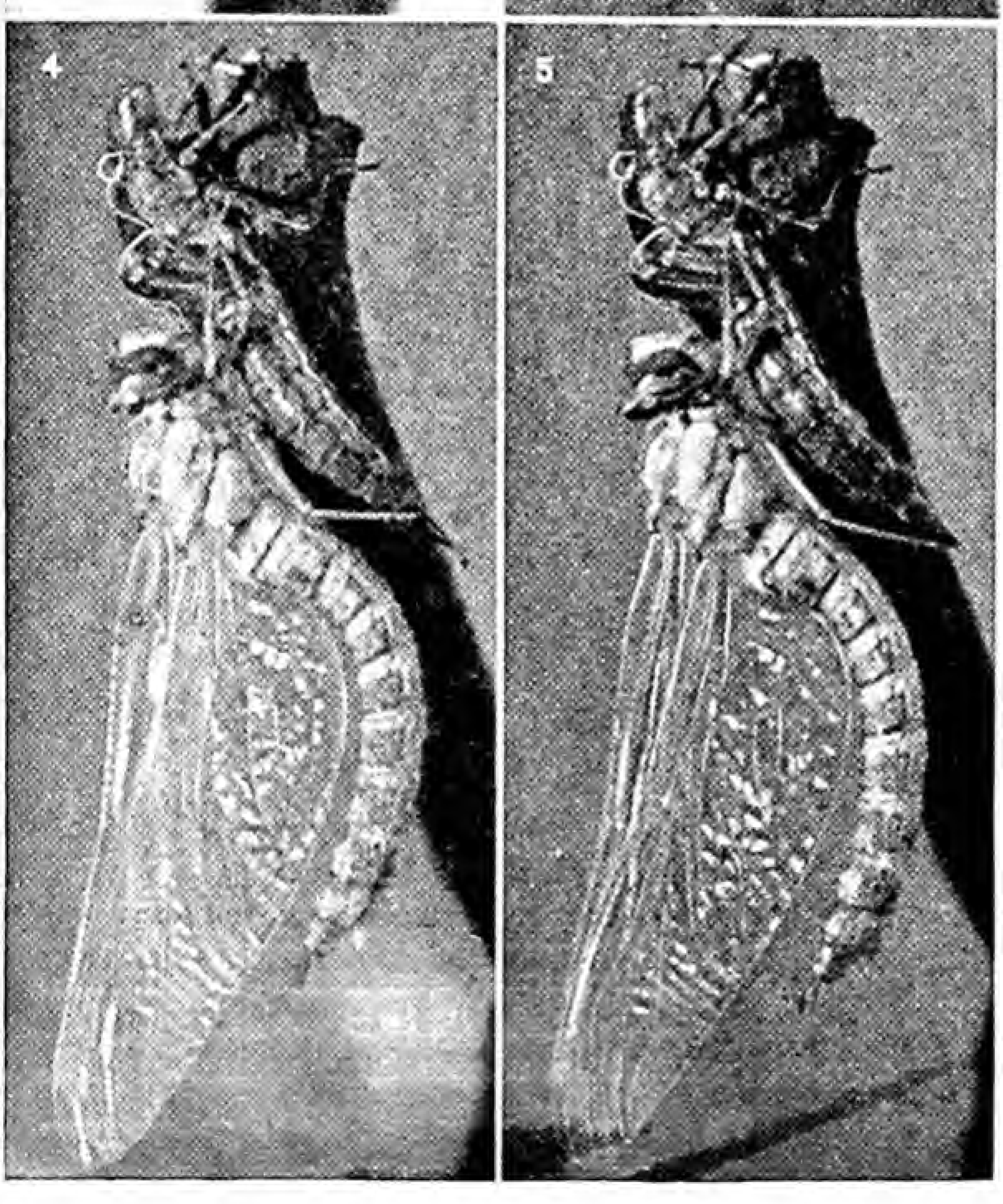
Now, we have seen already that land animals have to take measures to get enough water, and it follows that it is undesirable to lose more than necessary or the animal will dry up. So it is not surprising to find that land animals have special organs, small but of high efficiency in the absorption of oxygen, tucked away inside themselves to prevent too much evaporation of water.

Animals apparently living on land but without these special organs, like earthworms, appear to be exceptions, but this is not so. They are living in soil, which is almost as wet as water, and they obtain their water and oxygen just as though they were in water. Many species of earthworms do, in fact, live in ponds and rivers.

How Living Things Grow

The next activity to consider is that of growth. Growth is very difficult to visualize and it is not at all easy to define what are the fundamental structural requirements of a growing animal. It is probable that we know more about the chemical requirements than the purely biological ones. A few points, however, do stand out. First, that the growing animal must be able to





FINAL STAGE IN DEVELOPMENT OF A DRAGON-FLY

When an animal goes through two or more stages in developing from the young to the adult form it is said to undergo a metamorphosis. The dragon-fly is an example of complete metamorphosis. Its life history is told pictorially on page 2. The above series of photographs, taken at intervals of ten minutes, shows its rapid expansion after shedding the nymph skin. As the newly-emerged dragon-fly hangs on to a twig, the wings are blown up by fluid pumped from the body, while the outer skeleton dries and hardens. Soon it is ready to sail away on its brief span of life.

function as a living organism in its environment.

It cannot be incomplete to the extent that it is unable to function properly. There is, therefore, a general tendency for growth to take place, not at the ends of an animal or at the surfaces or ends of parts, but a little way back from the ends or surfaces. This is not quite so marked in soft tissues, where the addition of cells by division can be fairly easily taken up, as it were, but is very noticeable in harder parts.

Growth is Continuous

The next point is that growth is essentially a continuous process. It is brought to an end, not by reason of anything in its own nature but because other factors impinge upon it. Thus, in vertebrates, we find that those living in water, whose bones serve only the purpose of providing anchorage for the muscles and tendons and do not take any weight of the animal, growth is continued long past maturity, in fact, almost until death.

Thus we find occasionally enormous specimens of fish which have for one reason or another been able to live for a very long time. In the land vertebrates, however, where the bones have to take all the weight of the body, they must be finished off, as it were, and made firm at a fairly early age when growth, to all intents and purposes, ceases; this is often about the time of sexual maturity or a little later. Such animals have a maximum size which is fairly constant for the species. In birds, where rigidity of the skeleton is essential as soon as they begin to fly, growth is extremely rapid at first so that they are practically full grown when they leave the nest (in common nesting birds only ten days after hatching!).

Rate of Growth

Not only does the rate of growth vary, but also it varies in different parts of the body of the animal. Thus, at different times during the course of development and growth of an animal, the parts of the body bear very different proportions one to another. A very well-known instance is the legginess of calves and colts. The legs of these animals are very long indeed compared to the head and trunk when the young are born. It is generally considered to be an adaptation favourable to the species, because these animals depend on speed to escape from their enemies.

Other examples are not so obviously adaptive. In man, the proportion of head to hands varies considerably during life. At birth, the head is very large and the hands small; when adult, the hands are much larger in proportion. The growth need not be continuous; for instance, in deer little increase in total size and weight takes place after a few years, but the size of the annually produced antlers continues to increase enormously until they become almost a burden to the old stag or buck.

Almost as a corollary of growth is the process of reproduction. We have seen that growth is brought to an end largely because other processes come to take more out of the animal than the animal is able to obtain. This necessarily results in death and reproduction is a process whereby animal life is, as it were, given a fresh start at a level where growth, once again, is the dominant process.

Producing New Life

Reproduction is simply the production of new, young forms with similar potentialities to those possessed by the parent when it, too, was young. In the majority of animals, this is accompanied by the sexual process which appears to add to the rejuvenating action of reproduction and also allows necessary admixture of characters found in different individuals of one species.

Turning now to other daily activities of animals we see that animals to obtain food must either move in search of it or, by the production of water currents or similar devices, cause the food to be brought towards themselves. In this respect, animals differ fundamentally from plants. We find that animals have developed a type of cell for which there is no parallel to be found in plants; the muscle cell.

The muscle cell (or in mass, muscular tissue) is the most successful method of producing movement evolved in animals.

FLAMINGO PARENTS AND THEIR EGGS

All animals that reproduce sexually are derived from the egg, or ovum, of the female, but in mammals (with a few exceptions) the eggs are retained and nourished in the mother's body. Birds lay eggs containing food and which are provided with shells in which the embryos develop. Flamingoes lay one or two chalky-white eggs on conical nests.

MILKWEED FLOSS TAKES NO CHANCES

Plants have various ways of ensuring survival of their offspring. The seeds of the milkweed floss are enclosed in pods, which burst when ripe and the seeds are scattered in all directions. Some fall on fertile land where they germinate and grow.

It is not, however, the only method. Several others have been evolved and at least one of these, particularly suitable for inducing movement in particles outside the animal body, is quite widespread throughout the animal kingdom. More will be said about this subject in Chapter VI.

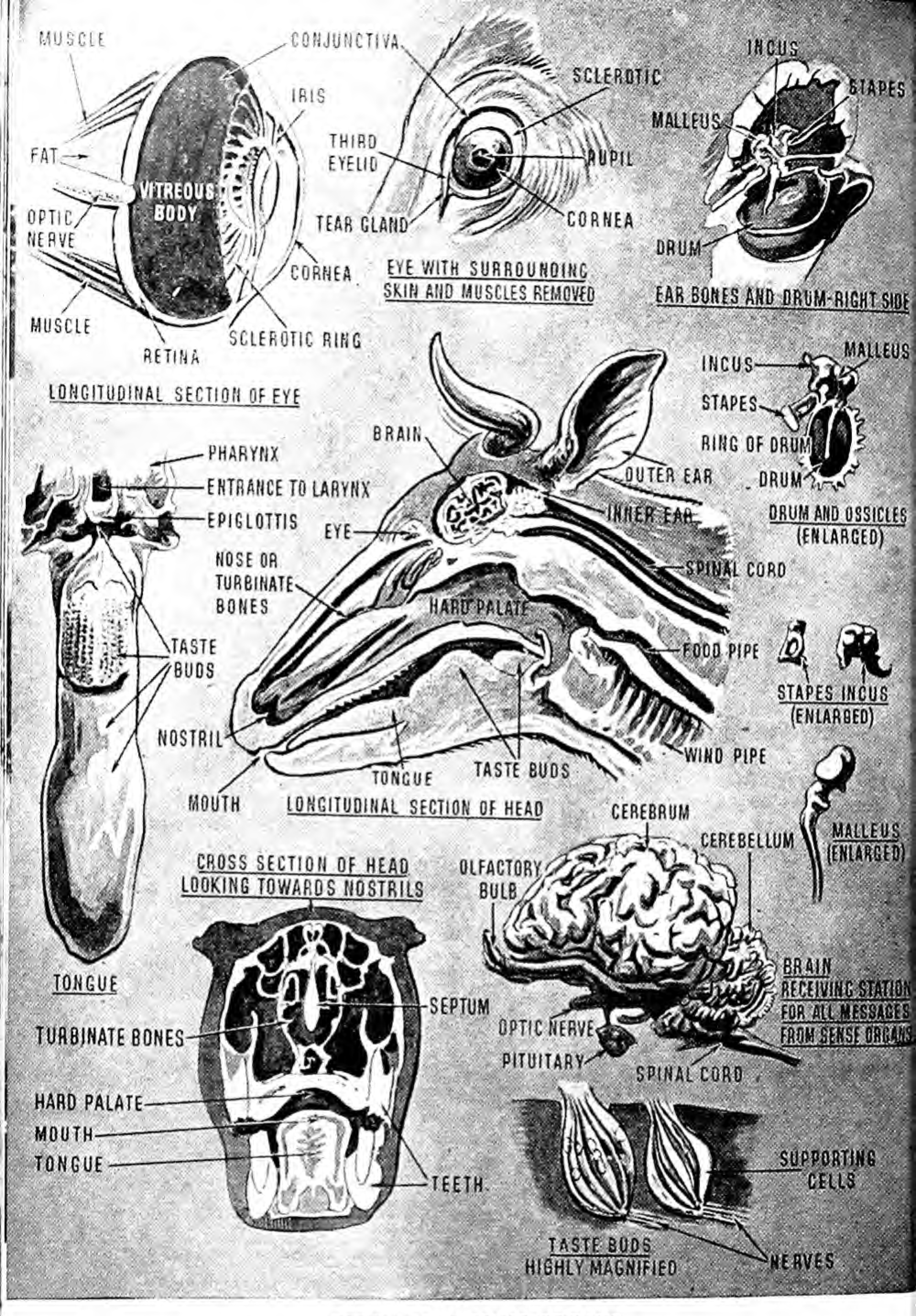
Since the animal moves in its environment, it is obviously an advantage if it is able to perceive something of that environment. By doing so, it can utilize its power of movement to select, at any rate to some extent, an environment which is most suitable to it.

We thus find in most animals another system, absent in plants, the nervous system, usually consisting of specialized sense organs, sensory nerves, a central co-ordinating nervous tissue and other nerves (motor) which control the reactions of the animal to the stimuli received.

The nervous system is capable of developing great complexity even in small animals like insects, and we are only on the fringe of knowledge of how it really works.

As a result of all these activities, feeding, digestion, breathing, growing, reproducing, moving and feeling, the animal produces waste products it no longer requires, the retention of which within the living protoplasm may be definitely injurious. The disposal of these waste products is known as excretion and may take place by many various methods. The two most commonly found are the discharge of carbon dioxide as a gas or in solution and of nitrogen as ammonia or urea dissolved in water. Less frequently, we find waste products deposited as solids, insoluble in water, within the animal's body where they can do no harm.

It will be clear from the foregoing very brief survey that these activities are not



SPECIALIZED SENSE ORGANS

Most animals have specialized sense organs for receiving impressions from the outside world. These vary in complexity according to the degree of complexity of the animal. The picture shows in detail the specialized sense organs of a cow.

only complex in themselves but must be co-ordinated in a precise manner if they are successfully to form the whole phenomenon of a living animal. No single one can be carried on without due regard to the others. We have thus come to the same conclusion about vital activities as we did about the physical parts, or organs, of living creatures. Therefore, let us remember again that the living organism, whether animal or plant, is the unit and not any one part of it.

Structure of a Plant

Most flowering plants possess two distinct parts which obviously live under entirely different conditions; one being the shoot, as it is termed, consisting of stem, branches, leaves and flowers, all growing above ground, surrounded by air on every side, and during the hours of daylight exposed to sunshine; while the other part of the plant, the root, is embedded in the soil and lives in complete darkness. Two further points of distinction are that the parts of the shoot—stem and leaves—are green; while the root and its branches are pale, dirty white. Moreover, while the branches of the root are all similar in appearance, the stem bears different kinds of branches, some with thin flat outgrowths known as foliage stems and leaves, others terminating in flowers.

On close examination of the root, it will be seen that there is often a main portion which is a direct downward continuation of the shoot or stem. It forms the main axis of the root and bears side branches, or lateral roots as they are termed, which grow outwards and slightly downwards; while in a fully mature plant, these lateral roots in turn will be found to bear finer branchlets which spread abroad in all directions. With the help of a good pocket lens it is possible to see that numerous minute, colourless hairs grow out just behind the tips of both the main and lateral roots and rootlets; and these hairs play a most important part in the life of the plant, for through them water and mineral salts in solution are absorbed from the soil.

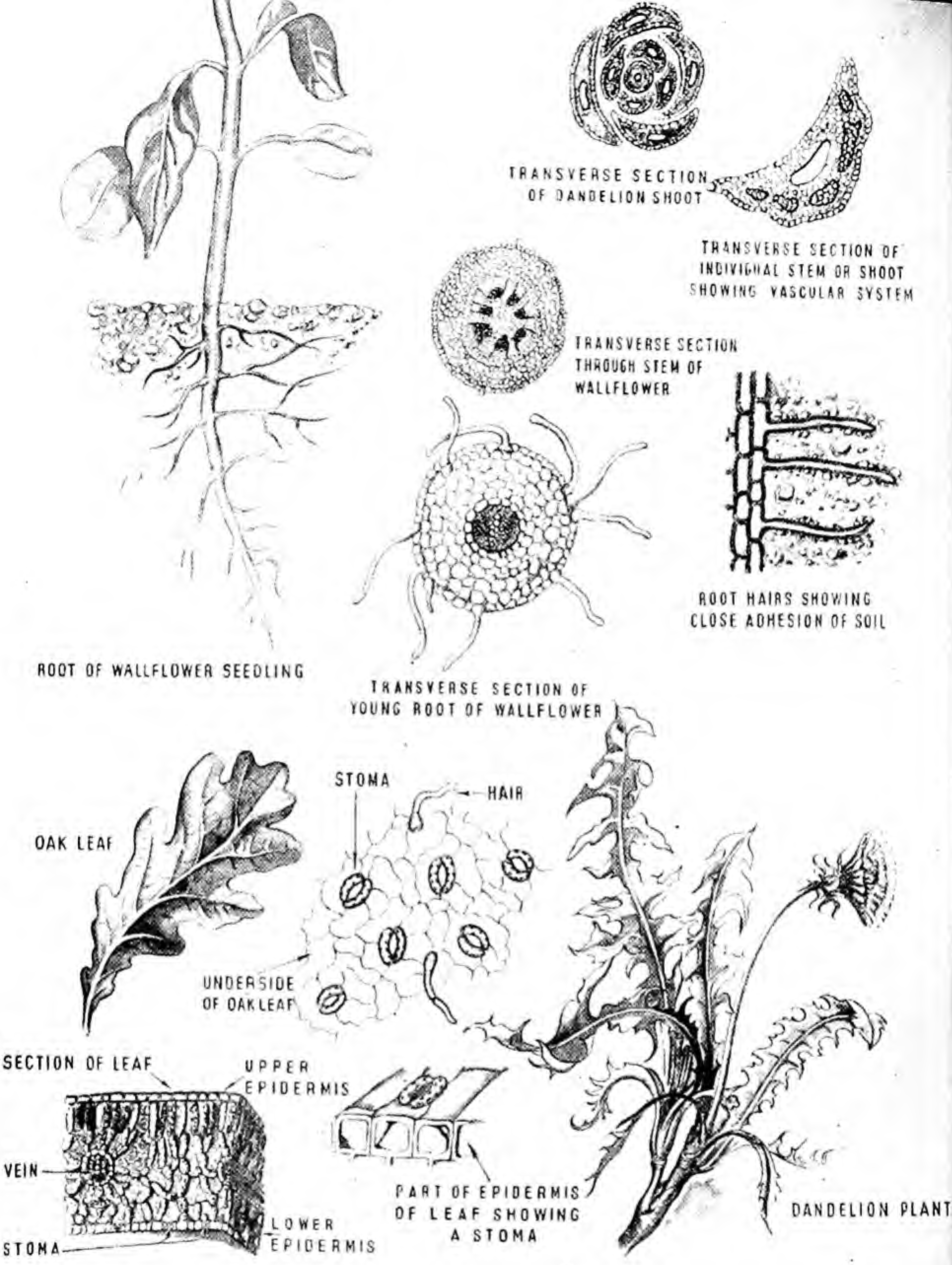
The root tips are always growing, lengthening, and pushing their way through the soil, and each tip is protected by a hood-like covering of cellular tissue, called the root cap. If the surface of the main root be gently scraped, it will be found that while the outer part consists of a soft substance or tissue easily removed, eventually a harder central core is reached which runs the entire length of the root and connects with the stem; while if we cut vertically down this central core and examine it with our pocket magnifying lens, we shall be able to make out that it is composed of bundles of thread-like strands, water-conducting vessels.

Turning now to the aerial part of the plant, the shoot, we can at once distinguish a vertical main axis, as in the root, bearing lateral branches which grow outwards and upwards, varying in number and position according to the type of plant that we are examining. In some plants it is easy to see that these lateral branches grow out from the main stem at regular intervals and in a gradually ascending spiral, while in others it is less obvious; or the lateral branches may be replaced by leaves which again will often be found to be more or less conspicuously spiral in their arrangement on the stem, so that they do not entirely overshadow one another.

Rosette Leaf Arrangement

We see a further modification in such familiar wayside weeds as the dandelion and the plantain, where numerous leaves arise close together at the base of the stem so as to form a rosette on the surface of the ground, from the centre of which one or more slender vertical stems arise, bearing the flowers or inflorescence.

On attempting to scrape away the surface of the stem in the same manner as we did with the root, almost at once we shall scrape down to a circle of narrow, stringy strands of harder tissue which run the entire length of the stem and branches, and are the continuation of similar strands already observed in the central core of the root. On cutting across the shoot with a sharp penknife, we shall see that these strands are arranged, and appear to the naked eye, as a variable number of pale



FOOD MANUFACTURE IN GREEN PLANTS

Every part of the plant is in some way necessary to the other parts but each part has its own special uses. The leaf is important because it is in the leaf that the process of food manufacture largely takes place. Starch is formed in the leaves through the action of daylight and chlorophyll upon water from the soil and carbon dioxide from the air. Water is drawn up through the pipe lines of the root and stem and carbon dioxide enters the leaf through the stomata in the epidermis. Some of the illustrations are greatly magnified.

greenish dots around the edge of the cross-section, while the actual central portion of the stem is composed of soft tissue; in fact, just the opposite to the arrangement of the tissues in the root.

Now, these strands of tissue which run from the main root and rootlets up and throughout the stem and branches, and into the leaves where they form the so-called veins, constitute what is known as the vascular system of the plant. They are composed of specialized cells or vessels, more or less tubular in shape, and may be said to resemble an elaborate and very perfect system of pipe-lines through which the water absorbed by the root hairs is carried to every part of the plant; the pipes up which the sap ascends, and through which food materials—starch, sugars and other carbohydrates—are conveyed and made available for immediate use or storage.

Having gained an outline of the general structure of the plant, we must now consider the functions performed by its different parts in the process of life and growth. Quite obviously, one of the important parts which the root has to perform is that of anchoring the plant securely in the soil, and for that purpose, being liable to stress and strain, the root must not readily snap or fracture. This danger, as we have already seen, is guarded against by the presence of the central core of vascular strands which are relatively tough and resilient. In the stem, on the other hand, the vascular bundles occur nearer the exterior, round the outer edge as it were; an arrangement rendering the aerial stem and branches better able to cope with bending strains in all directions caused by the action of the wind. Moreover, the leaves, which naturally offer a relatively large surface of resistance to the wind, have their delicate tissues strengthened and supported by the complicated network of veins or strands of vascular tissue, which are a continuation of those running throughout the root and stem.

Absorption of Moisture

The second and equally vital function of the root is the absorption of water and, in very weak solutions, of certain mineral substances present in the soil. A large proportion of the moisture drawn up through the pipe-lines of the vascular tissues escapes in the form of water vapour from the surface of the leaves, while the remainder is used in the building up of fresh tissues in the processes connected with growth and assimilation. As we shall learn in a later chapter, the surfaces of the leaves are perforated by vast numbers of very minute pores which are usually more numerous on

JACK-IN-THE-PULPIT

Three stages of growth. A striped flowering spathe rises between two long-stalked tripartite leaves.

OYSTER MUSHROOMS

Fungi growing on a fallen elm. They have shell-like caps and short thick stems. The gills are white. Fungi are organisms devoid of chlorophyll living on decaying plant or animal material.

the under than the upper surfaces; and these pores, or stomata as they are termed, vary in the size of their openings at different times and under varying conditions, so that actually they play a very important part in controlling evaporation of moisture. They are usually wide open during the daytime, and almost or completely closed at night; and it is through them that most of the water-vapour escapes from the plant into the surrounding atmosphere. However, as we shall learn later on, there are internal as well as external conditions affecting the rate of water-loss and the whole complex process is known as transpiration.

One of the most striking differences between the aerial and the underground parts of the plant, is the green coloration of the former, and particularly the leaves. This is due to the presence in the living tissues of the plant of a pigment substance called chlorophyll, of vital importance in the processes of nutrition, and only formed and active under the influence of daylight. Plants that are grown in cellars or rooms from which all daylight is excluded, soon assume a pale, starved and sickly appearance, showing that daylight is absolutely essential both for the formation of chlorophyll and the production and utilization of food-substances.

Starch, which is of primary importance to the life and growth of the plant, is only formed in the leaves through the action of daylight and chlorophyll upon the carbon dioxide drawn from the air and some of the water drawn up into their tissues from the soil; the air chiefly obtaining access to the leaf tissues through the leaf-pores or stomata. In the process, oxygen, which is a by-product of this chemical action, is returned to the surrounding atmosphere. This building up of starch and similar substances from carbon dioxide and water, is known as carbon assimilation, and on account of the part which the action of daylight plays in the process, is frequently termed photosynthesis. Actually, carbon assimilation is the first step in the nutrition of the plant, leading on to the formation of more complicated substances, carbohydrates and the like, in the ultimate production of which the mineral salts absorbed in solution by the roots from the soil, also play an important part.

Life Essentials

The substances necessary for the sustenance and growth of the green plant, and for the maintenance of its healthy life, are thus obtained from the air and the soil. The roots in the first place anchor the plant in the ground and absorb water containing mineral salts in solution; while the leaves, through the action of daylight and their green colouring substance chlorophyll, separate the carbon dioxide from the

atmosphere, and with some of the water utilize it in the production of food and other substances necessary for the continued growth and nourishment of the plant.

One vital process in the life of the plant which so far we have not considered is respiration, which is just as essential to the existence of the plant as for all forms of animal life. In respiration, the exchange of gases is just the reverse of what takes place during assimilation, the oxygen being retained while the carbon dioxide is returned to the surrounding atmosphere. Throughout its entire life, day and night, the plant is taking in oxygen and giving off carbon dioxide; but during the hours of darkness the amount of carbon dioxide given off is greater than in the daytime, because of the absence of photosynthesis.

From the above general outline we are able to realize that the vital processes of life in the plant bear a marked similarity to those of the animal—breathing, the gathering of material and its assimilation in the processes of body-building and nourishment—though the manner of obtaining, and the kind of primary material necessary for the latter function is profoundly different. Broadly speaking, the marked characteristics of flowering plants, distinguishing them from animals, are the external development of the plant-body which serves to absorb food; the cellulose walls of the cells, and the chlorophyll of the leaves which, under the influence of daylight, enables the plant to build up from inorganic compounds the organic substances necessary for the maintenance of life. Animals, on the other hand, cannot do this, they are absolutely dependent for their nourishment upon organic materials, and consequently upon plant-life, for their very existence.

The bacteria and the higher fungi, being devoid of chlorophyll, are unable to separate the carbon dioxide from the atmosphere. Consequently, they are largely dependent upon supplies of organic substances for their existence. Those fungi which are parasitic in habit obtain their organic food supplies at the expense of their living hosts; while the saprophytic fungi live upon dead and decaying vegetable and animal matter. Many species, in fact, play a very important part in the breaking down of such substances and thereby assist in the enrichment of the soil.

Test Yourself

1. What characteristics distinguish living from non-living things?
2. Name some of the activities in which living things engage in the pursuit of food.
3. What is the most important difference between the two major divisions of the living world?
4. What is protoplasm?
5. What are the characteristics of a cell?
6. How do animals dispose of waste matter?
7. How do plants and animals grow and perpetuate life?
8. Describe the most noticeable external and internal differences between stem and root, and why they are necessary.
9. Why is chlorophyll so important to the plant?
10. Where and how does a green plant obtain carbon and oxygen?
11. What important work is carried out by all green plants during the daytime, and what vital function is in continual operation day and night?
12. In what way do bacteria and all other fungi differ from all green plants in regard to nutrition, and in obtaining food?

Answers will be found at the end of the book.

AMERICAN OPOSSUM

Opossums are members of the sub-class of Mammalia called Marsupialia, animals which carry their young in pouches. They are the only marsupials to be found outside Australasia. They are small, nocturnal, arboreal animals with long prehensile tails.

CHAPTER II

HOW ANIMALS ARE CLASSIFIED

BEFORE we can really begin to talk about individual animals we must decide what to call them. This is one of the earliest problems man had to face as he struggled out of prehistoric times. One story of an early attempt is described in a rather idealistic fashion in the Book of Genesis. Adam is supposed to have given all the animals of Creation their names. Whether it was Adam, or someone else, does not matter; somebody had to do it, and, as a matter of fact, people are still doing it as more and more animals and plants are discovered. At the present time, there are more than a million species of animals known and described; about half of these are insects.

Just look at the last sentence for a moment. Three words have been used—species, animals and insects—which need looking into. What is meant by a species? Are insects included in animals? Is, say, a spider an insect? If we can answer these questions we shall be much nearer understanding how classification is carried on.

Let us ask the first question in a different way. Supposing we have a tiger, a leopard, a tabby cat and a manx cat, how many species are represented? The answer is three; the two cats belong to one species, so that there are three distinct kinds of animal. The differences between the tabby cat and the manx cat are not enough to make them into separate species. They have the same habits, they interbreed (if one is male and the other female) and their structure is the same, except that one has a long tail and the other a short one.

We see, then, that whether or not two animals belong to two species is a question of degree. If the differences are big enough or numerous enough, we say there are two species. Is it then all a matter of opinion? No, not entirely. Many of the early naturalists made mistakes by grouping different species together because they did not know enough to recognize the differences. Sometimes members of one species have been put into two different species because differences, such as colour or shape, were so obvious that they appeared great in proportion to the likenesses.

Dissimilar Males and Females

Some of the South Sea butterflies have males and females so unlike that the two sexes were put into different species or even into different larger groups. This was because the naturalist did not know; he had never seen the two butterflies breeding together. In Britain, the silver-washed fritillary has a dark-green form, in sharp contrast with the usual orange-brown. All these green butterflies are females and we know that they breed with the more usual brown ones and belong to the same species.

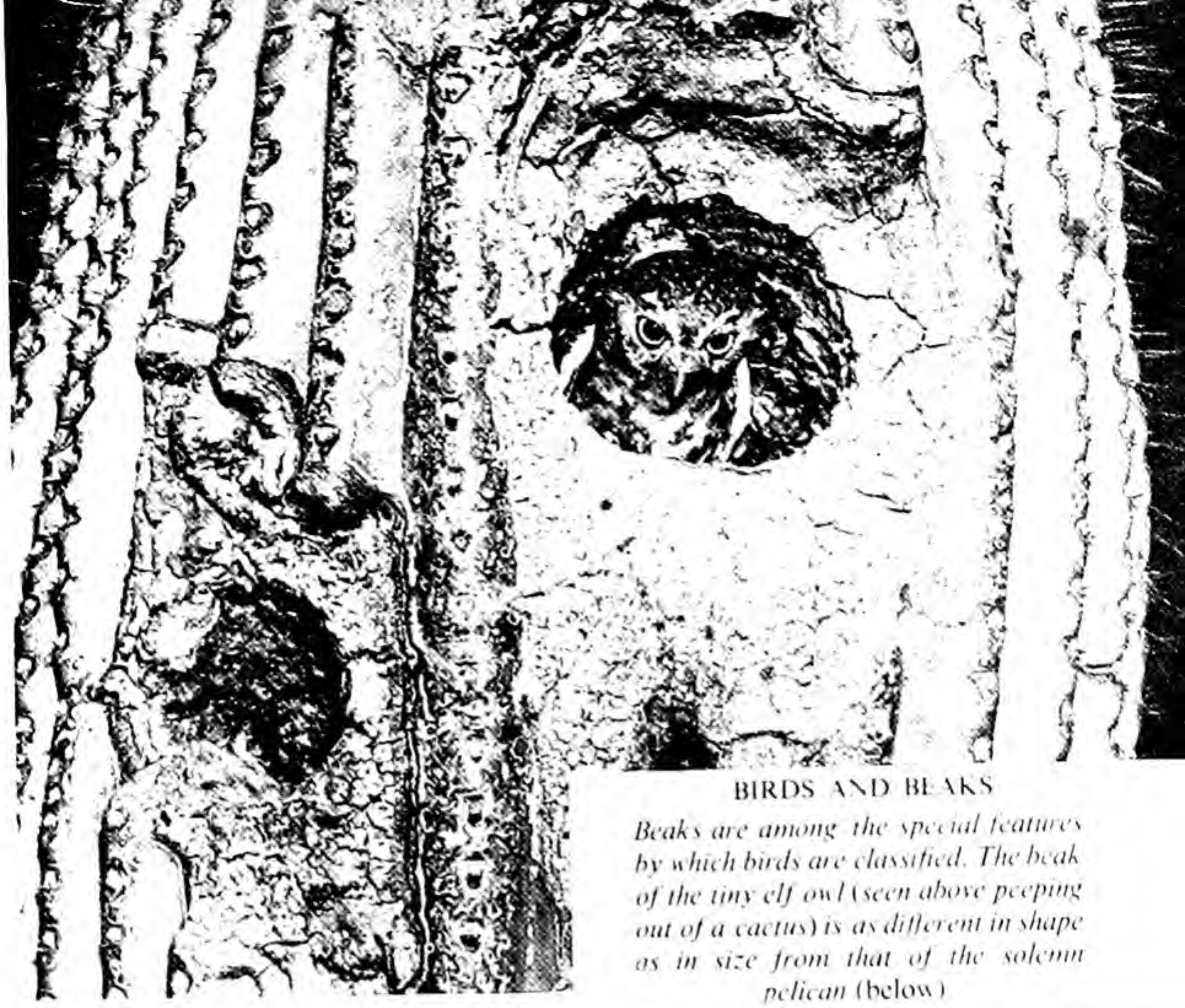
A casual observer would, however, put them into a different species until he had a little more knowledge. In the same way, we cannot use the same differences to distinguish between species in widely differing groups. Among birds we find different songs, different coloured feathers, different shaped beaks and legs. These features are no use at all to separate species among fish, which have neither song, feathers, beaks nor legs. We shall, however, find similar kinds of differences which can be used such as numbers of scales or shape of fins.

So we can see that the idea of a species is something to aim at and, in most cases, we can achieve it by getting to know as much about the animal as possible. A species represents a group of individual animals differing only in small ways and forming a fairly recognizable unit of animal (or plant) life.

Next, we come to the vexed question of what we mean by the word animal. Unfortunately, you will find that there are several usages in common speech, because most people who use the word do not mind what they mean by it precisely. If we are

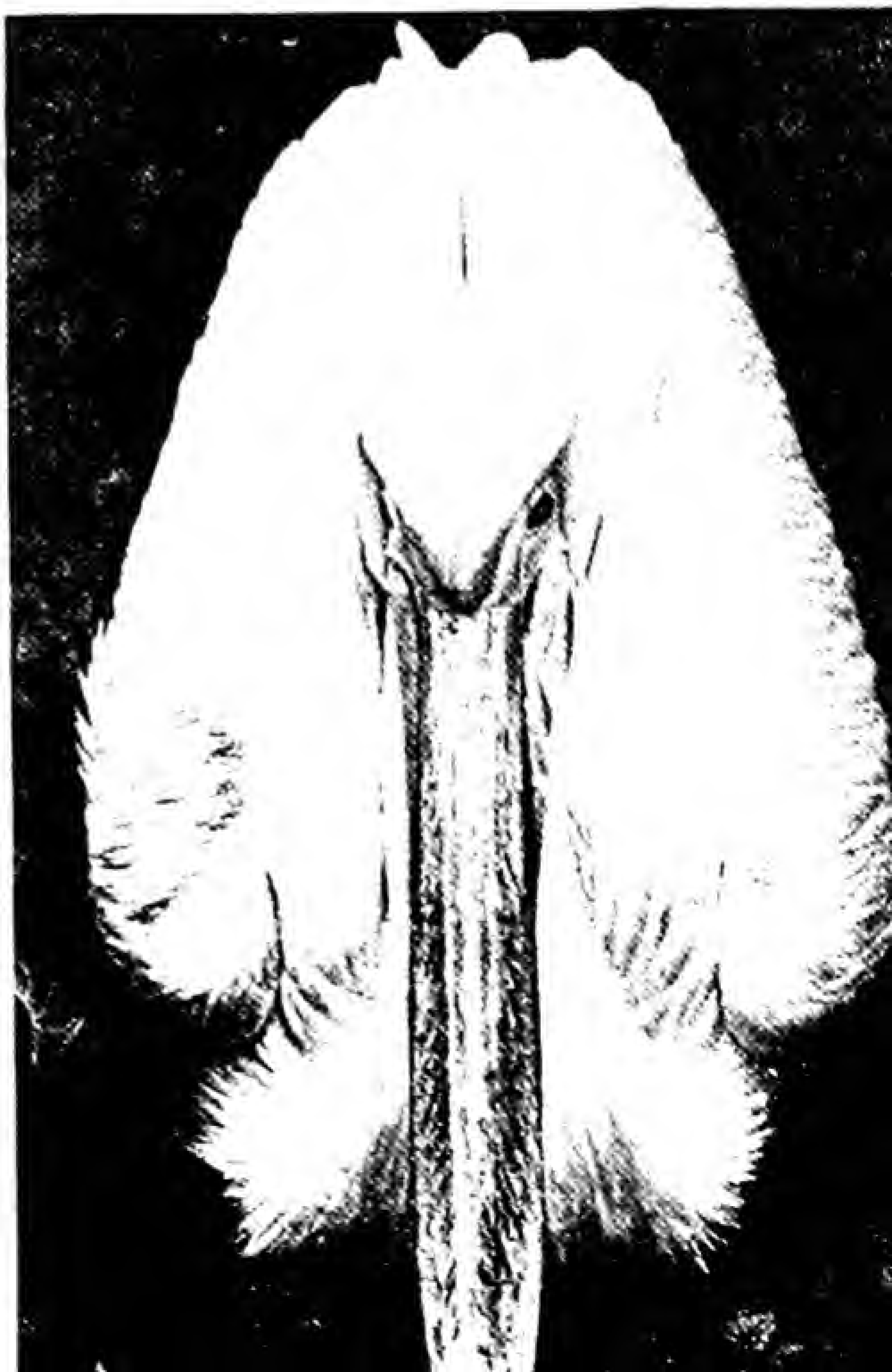
BRAZILIAN ANGEL FISH

Fish are classified according to such characteristics as form, scales, size and shape of fins, mouth and teeth. The angel fish seen from the side presents a great flat surface the effect of which is enhanced by its large fins. It is strikingly marked.



BIRDS AND BEAKS

Beaks are among the special features by which birds are classified. The beak of the tiny elf owl (seen above peeping out of a cactus) is as different in shape as in size from that of the solemn pelican (below)



going to talk about animals for the rest of this book, we should be more exact. There is no need to invent a special word or use a Latin one at this stage, because we can continue to use the word animal if we know its exact meaning. The sense in which we will continue to use it has already been defined in Chapter I and will, therefore, include insects, worms, jellyfish and every other living thing which lives in the way an animal should!

To answer our third question is now fairly easy. Between the "grades of species" and "animal kingdom" we must obviously have a number of other grades so that we can conveniently refer to larger and larger groups. The names of these grades have been chosen and defined through the many years during which naturalists have been working.

Nearly all of them mean a group of some kind, and it is only definition which makes some of the names refer to large groups and others to smaller ones. Thus we find that a number of species are grouped into a *genus*

(Latin = a kind, kindred), several *genera* into a family, several families into an order, several orders into a class, classes into a *phylum* (Greek = race) and *phyla* into the animal kingdom.

It has taken a long time to decide what degree of differences are suitable to each grade. The task is not made any easier because some large groups have an enormous number of known species while others have very few. Sometimes, for convenience, and also to indicate real groupings of species, extra groups have to be inserted as sub-genera, sub-families, etc.

In the genus Bombus (bumble-bees), there are over 2,000 species in the world! So there are several sub-genera to break up this huge mass of species. In other groups there are very few species indeed, although the characters of the group are so important that they cannot be given a lower grading. In the class *Mammalia*, there are only about a dozen species of egg-laying mammal as against the thousands of mammals which produce their young alive. All suckle their young (hence the name, mammal = Latin *mamma*, a teat) but to lay eggs like a reptile or bird is so extraordinary that it must be recognized by a high grading even though there are so few species.

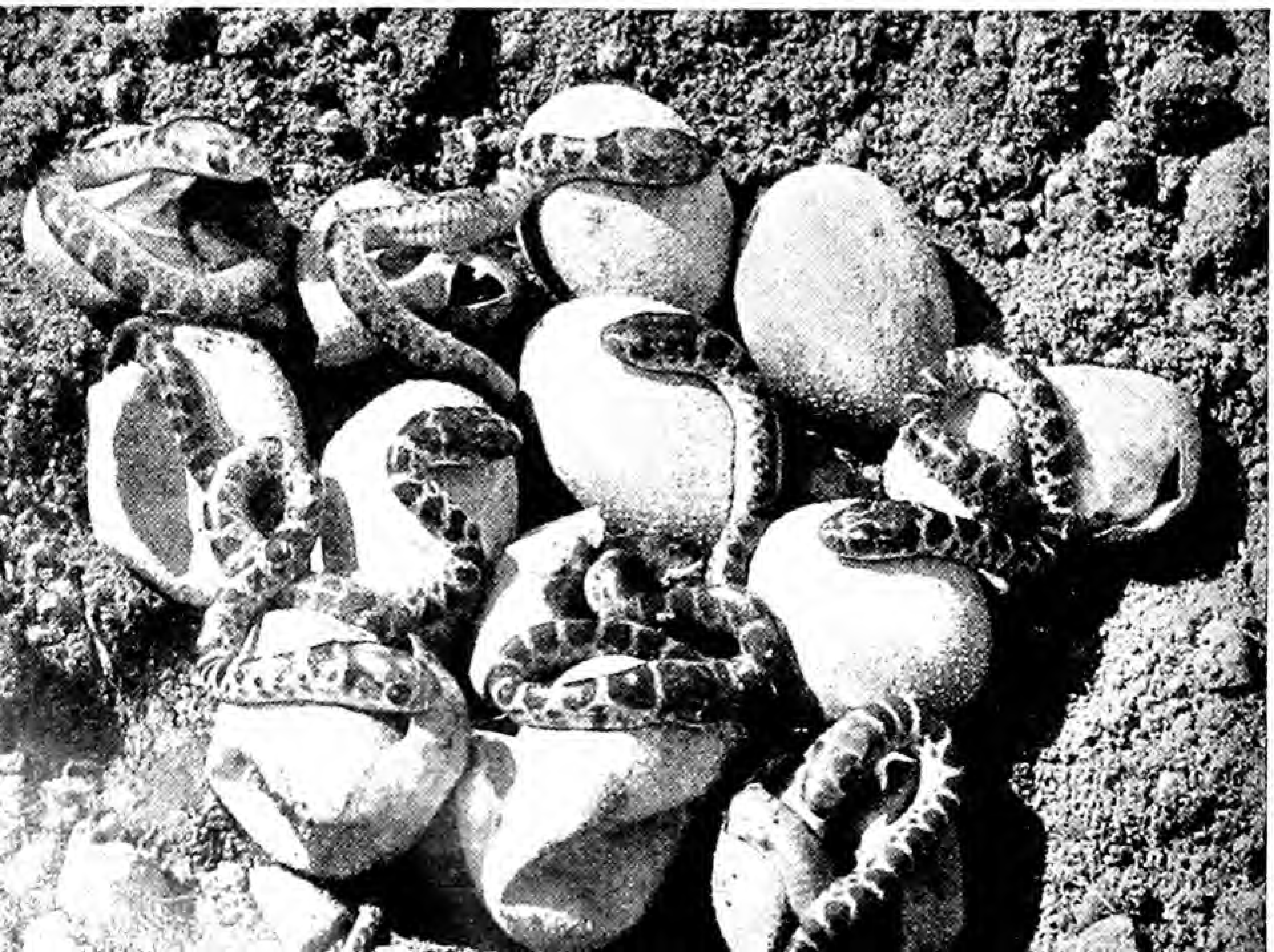
Why Latin Names?

There is another question which nearly everyone asks: why are all the names in Latin? Why won't common names do? The answers are quite simple; first, there aren't enough to go round! Take spiders for example; there are probably three genuine common names in English—garden spider, water spider and wolf spider, yet there are about 550 British species alone. What about the money spider? Well, that is another answer; it is not a spider at all, but a mite!

So often a common name is incorrect in this way. Water-fleas, for example, are certainly not fleas! Again, the same name or

YOUNG MILK SNAKES HATCHING

Strange as it may seem, some snakes give birth to their young while others lay eggs. After laying her eggs, the mother milk snake abandons them and leaves them to be hatched out by the sun. However, the young snakes are well able to fend for themselves.

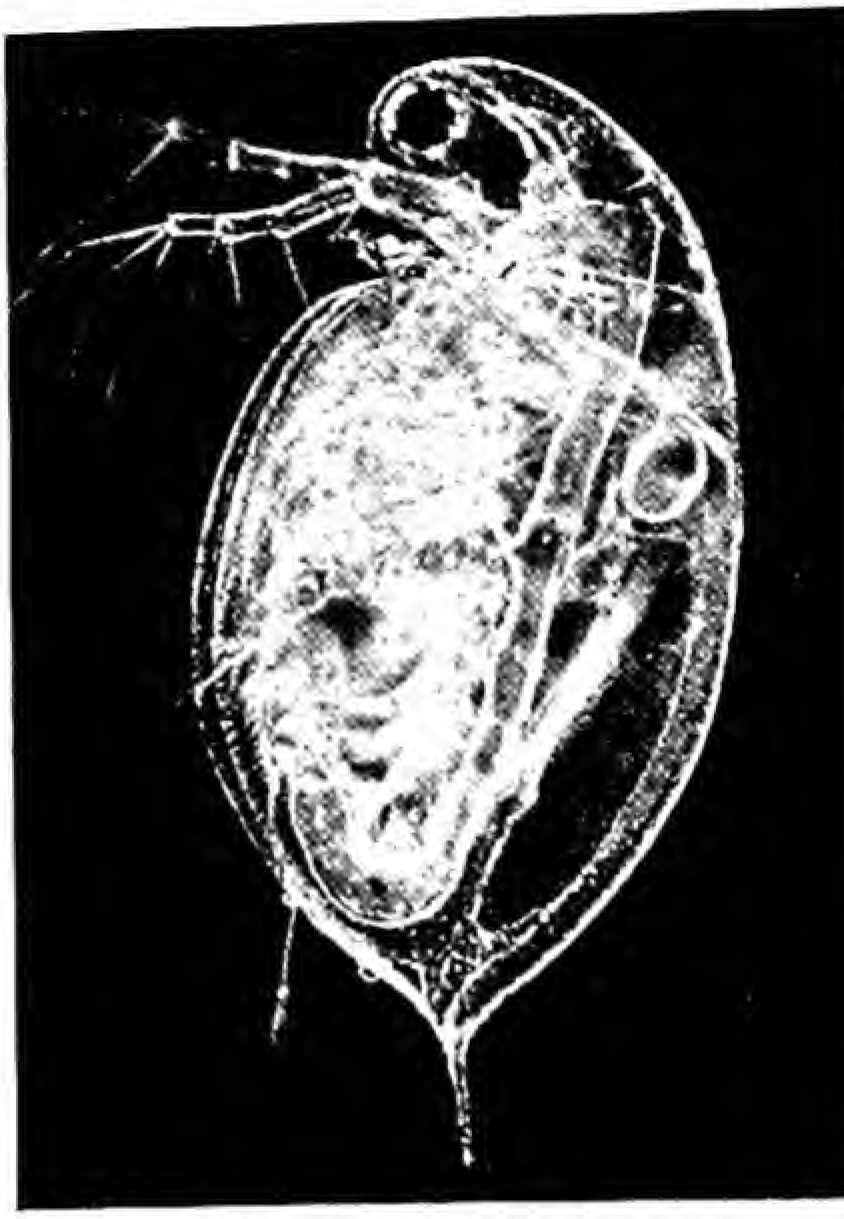


corresponding translation has a different meaning in different countries. We all know what we mean by a lion, but in the United States the name lion is given to the cougar, a mountain cat about the size of a leopard but uniformly sandy coloured.

In England, we have the terms butterfly and moth; generally to refer to day and night flying forms, although most people know that a few moths regularly fly in the daytime. If you look up the French translations you find the names *papillon* and *mit* respectively. The French, however, use these terms to refer to large and small forms whether they fly by day or night. And so the examples could go on almost indefinitely.

When the translators of the Bible came on the name of a small animal which burrowed in the ground, they used the English word of that day for rabbit—coney. Nowadays, coney does not refer to rabbit at all (unless you are buying furs!) but to the little African animal whose Latin name is *Hyrax*. No, there was only one thing to do, and that was to use names made from Latin or Greek which, being dead languages, could not have common or modern meanings altered or misapplied. It is nothing to worry about because it is the specialists who have to use these names most of all and the rest of us need only use them to be precise when we need to be.

Below are catalogued the names of the large *phyla*, with their principal classes and orders. In the right-hand column are placed the common names, or near-common names if real common names are missing, to give an idea of the sort of animals contained in these groups.



DAPHNIA OR WATER-FLEA

The water-flea is a minute aquatic crustacean and bears no relation to the common flea, which is an insect. Daphnia has a transparent bivalved shell. (Photomicrograph.)

Earliest Classifications

The earliest serious attempt to classify animals was made by Aristotle, about 350 B.C. His main groups were very much like those of today in broad outline, so that, even though there is room for opinion, you will see that, fundamentally, people who study animals and plants come to similar conclusions, because there are real differences underlying the artificial divisions into groups.

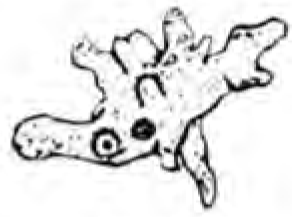
Then came the Dark Ages, and it was not until after the revival of learning in the fifteenth and sixteenth centuries (nearly 2,000 years after Aristotle!) that the task was taken up again. This was a great period of exploration and discovery. New animals were brought back from new lands and people became interested in their anatomy. It was not until the eighteenth century that serious attempts were made to construct a "Scale of Nature." The naturalists of those days (Buffon, Cuvier and Lamarck, all Frenchmen), tried to do two things at once. They tried to show that organic life was continuous in its grading from the simplest to the most complex stage of development and at the same time to divide it into categories; classes, orders, etc. Cuvier inclined to four great independent divisions of the animal kingdom. Buffon and Lamarck thought life more continuous, but all constructed systems of classification.

In the middle of the century came Linnaeus (a Swede). He it was who introduced order out of chaos, particularly by using only two names to identify an animal,

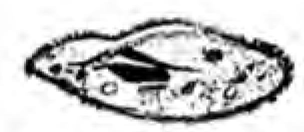
the generic name and the specific. Thus the house-mouse was called *Mus musculus*, lots of other mouse-like animals also having the generic name *Mus*, but only the house-mouse the specific name *musculus*. Out of eighty-eight species of mammal known in Britain to-day, no less than twenty-seven have specific names given them by Linnaeus. This gives some idea of the extent of the work of this great man.

PHYLUM I. PROTOZOA (Animalcules)

CLASS A.	**Rhizopoda**	Amoeba, radiolarians, foraminifera.
CLASS B.	**Mastigophora**	Whip animalcules, trypanosomes (sleeping sickness parasite), etc.
CLASS C.	**Ciliophora**	Slipper animalcules, bell animalcules, etc.
CLASS D.	**Sporozoa**	Malarial parasite, etc.

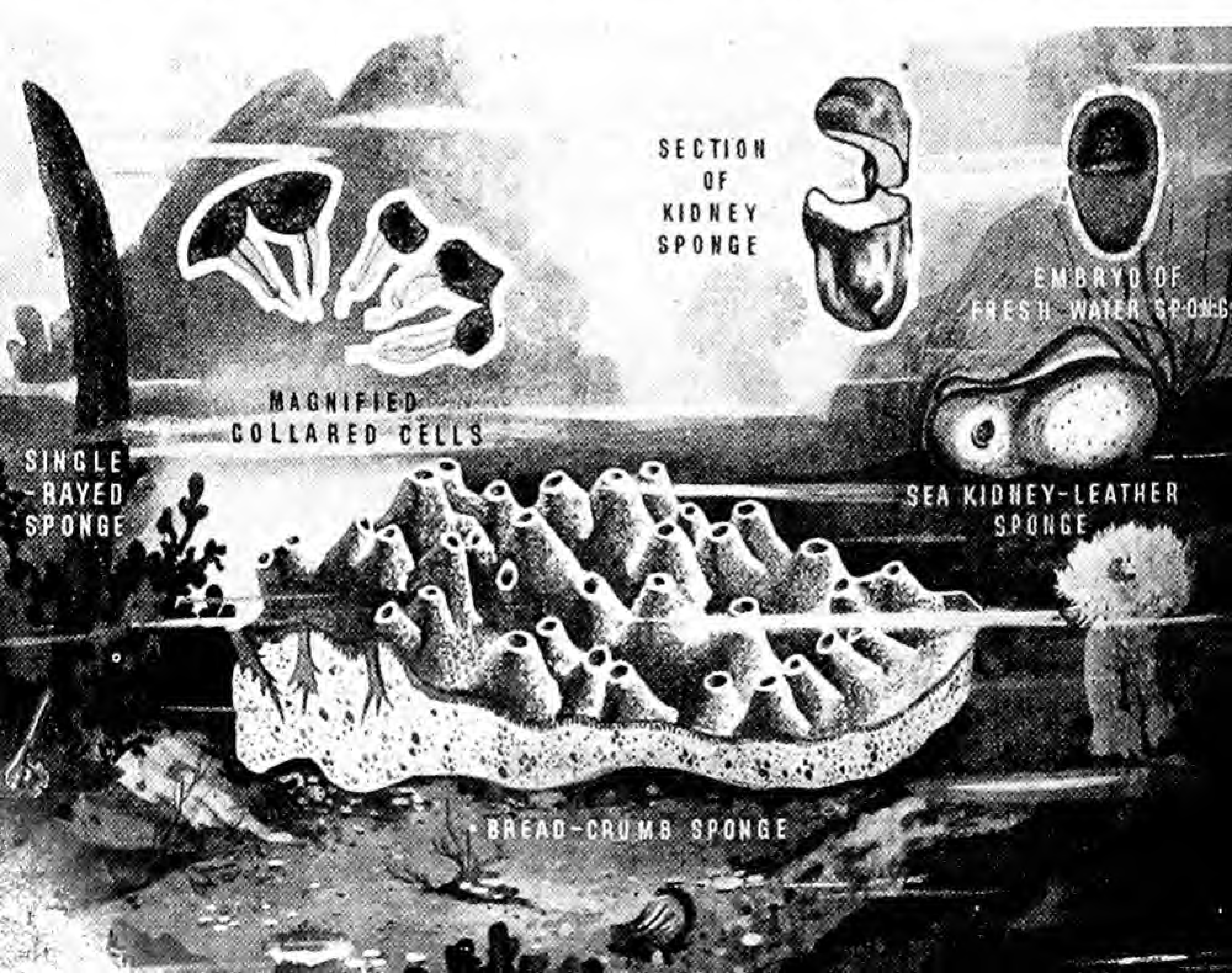

Amoeba.


Trypanosome.


Slipper Animalcule.

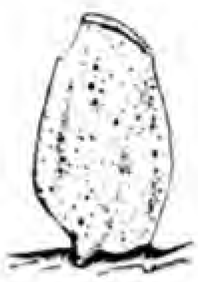
VARIOUS FORMS

There are thousands of different kinds of sponges, all of them living in water, fixed on stones, weeds, etc., in the sea, river or pond which they inhabit. Some of the deep sea sponges weave beautiful glassy baskets of delicate design, very different from the familiar



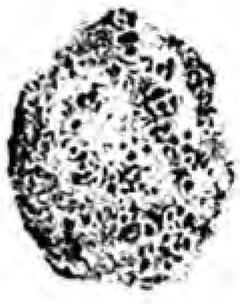
PHYLUM II. PORIFERA (Sponges)

CLASS A.	**Calcarea**	Calcareous or limy sponges.
CLASS B.	**Hexactinellida**	Glassy or flinty sponges.
CLASS C.	**Demospongia**	Bath sponges, etc.



Limy Sponge.

Glassy or Flinty Sponge.

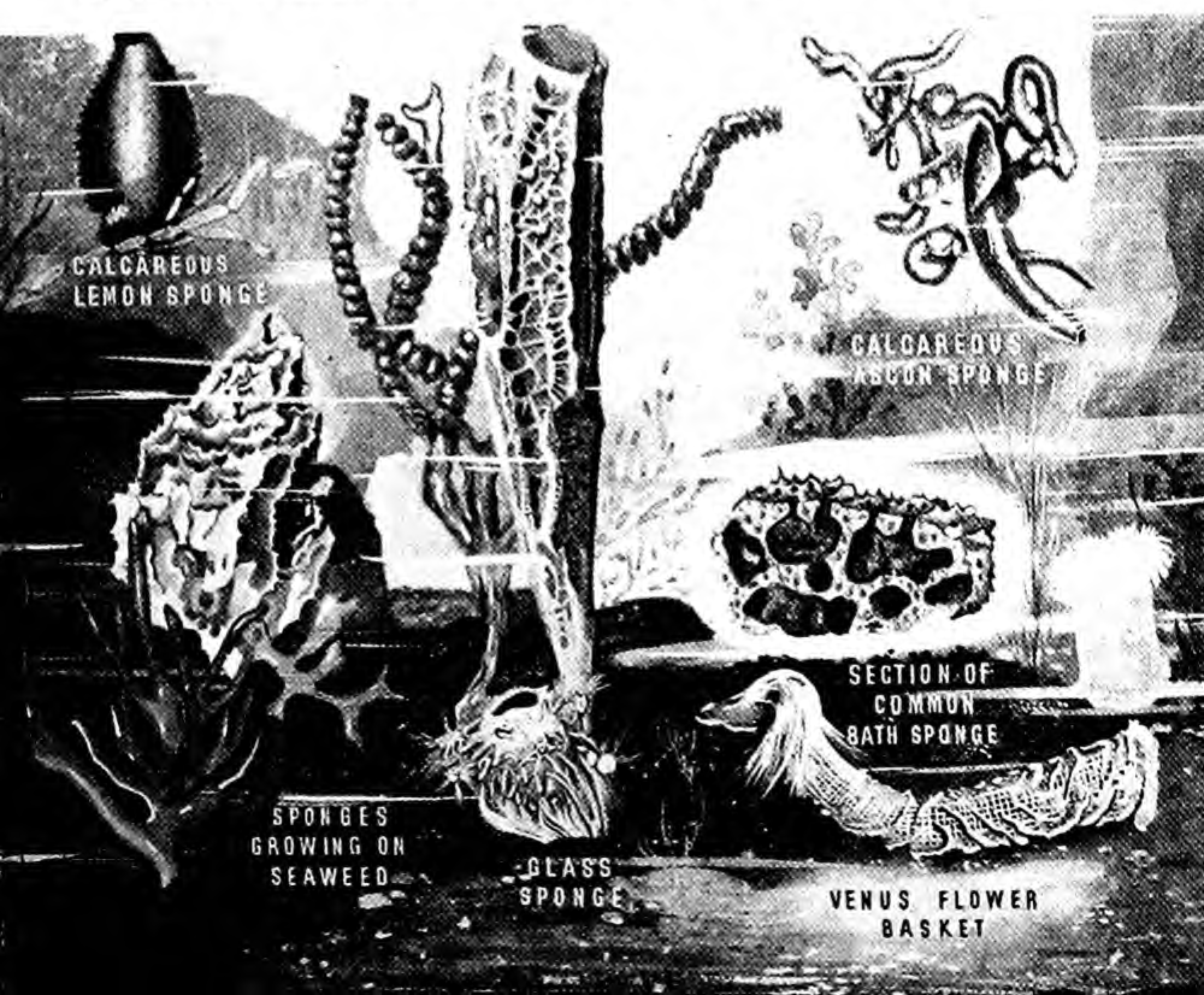


Bath Sponge.

PHYLUM III. COELENTERATA

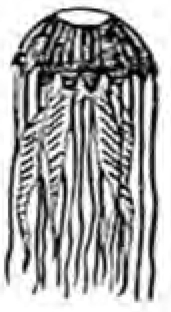
CLASS A.	**Hydrozoa**	Sea-firs, fresh-water hydra, Portuguese man-o'-war.
CLASS B.	**Scyphozoa**	Jelly-fish.

OF SPONGES
bath sponge which is actually the horny skeleton of a once-living creature. The sponges illustrated are not in actual proportion to one another. The ascon sponge is a tiny organism but Venus's flower basket, one of the best known glassy sponges, may be several inches long.

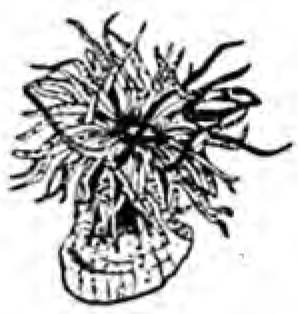


CLASS C.	**Anthozoa**	Sea-anemones, sea-fans, corals.
CLASS D.	**Ctenophora**	Comb-bearers, sea-gooseberries.

Portuguese Man-o'-War.



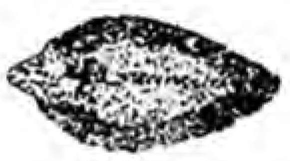
Jelly-fish.



Sea-Anemone.

PHYLUM IV. PLATYHELMINTHES (Flat-worms)

CLASS A.	**Turbellaria**	Planarians
CLASS B.	**Trematoda**	Liver flukes.
CLASS C.	**Cestoda**	Tapeworms.

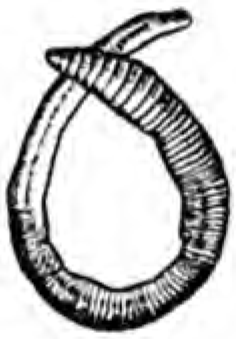


Liver Fluke.

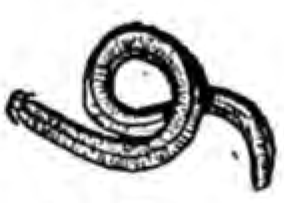
Tapeworm.

PHYLUM V. ANNELIDA (Ringed Worms)

CLASS A.	**Oligochaeta**	Earthworms.
CLASS B.	**Polychaeta**	Sea-worms, paddle-worms, rag-worm, sea-mouse, bristle-worms, lug-worm.
CLASS C.	**Hirudinea**	Leeches.



Earthworm.



Sea-Worm.

Leech.

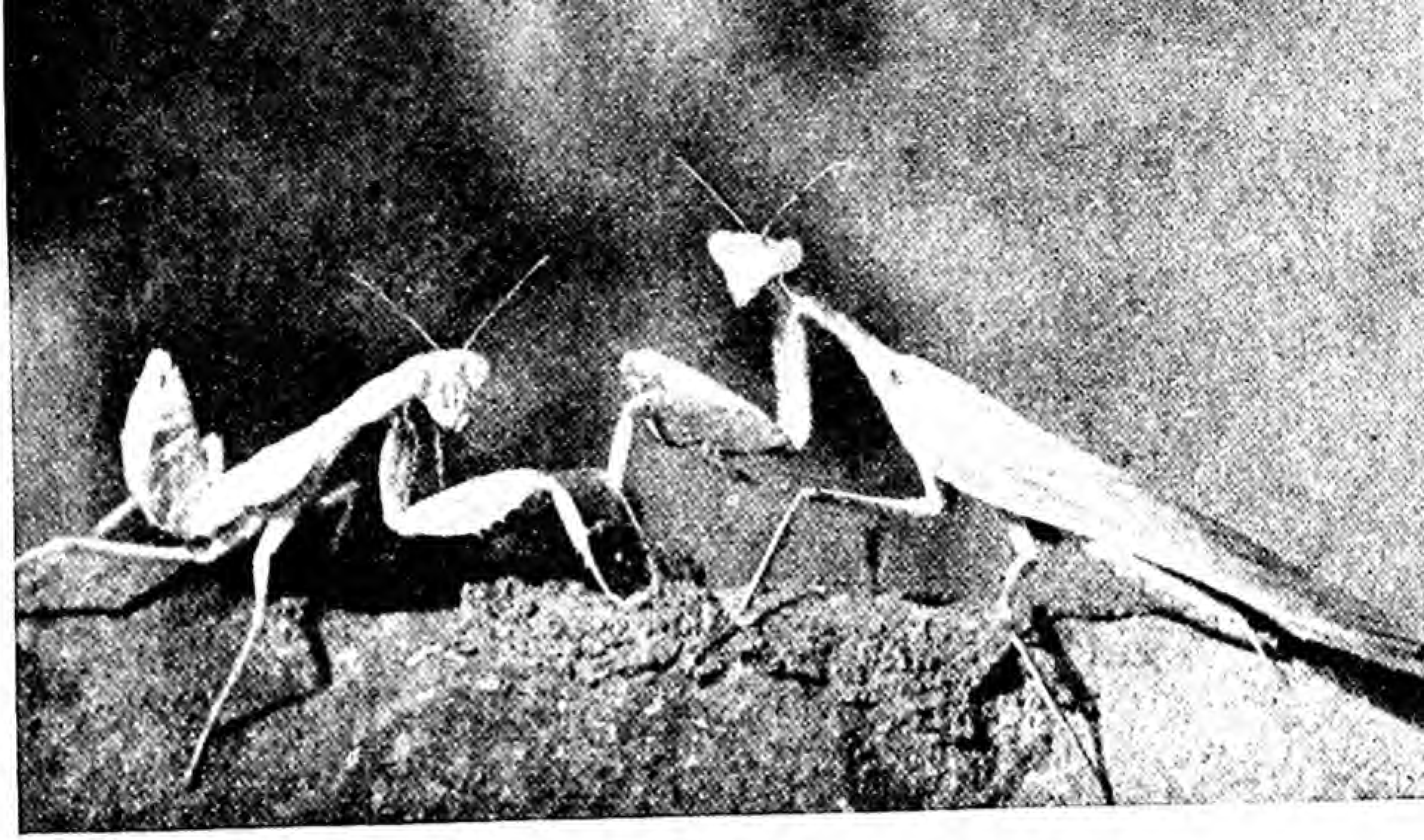
PHYLUM VI. MOLLUSCA (Shell-fish)

CLASS A.	**Pelecypoda**	Mussels, oysters, clams, scallops, cockles, ship-worms.
CLASS B.	**Gasteropoda**	Limpets, whelks, periwinkles, ear-shells, cowries, snails, slugs, sea-slugs.
CLASS C.	**Cephalopoda**	Squids, cuttle-fish, octopods, paper nautilus.

Scallop.

Cowrie.

Nautilus.



PRAYING MANTIDS FIGHTING

Mantids are carnivorous insects and extremely voracious and pugnacious. They fence with their sword-like forelimbs and frequently will devour one another. The praying mantis stands on its two pairs of hind legs, with the forelimbs folded in front as if in prayer.

PHYLUM VII. ARTHROPODA

CLASS A.	**Crustacea**	Fairy shrimps, brine shrimps, water-fleas, cyclops, fish-lice, barnacles, sand hoppers, fresh-water shrimp, wood-lice, kril, prawns, shrimps, lobsters, crayfish, crabs, hermit crabs.
CLASS B.	**Arachnida**	King-crabs, scorpions, harvesters, spiders, mites, ticks.
CLASS C.	**Prototrachiata**	(*Peripatus*)
CLASS D.	**Myriapoda**	Centipedes, millipedes.

Prawn.

Scorpion.

Centipede.

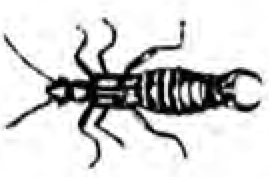
CLASS E. Insecta (insects)

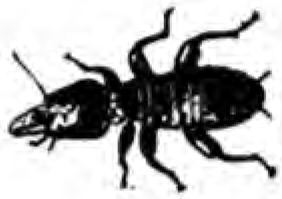
ORDERS.	1. *Thysanura*	Bristle-tails, silver-fish.
	2. *Collembola*	Spring-tails.
	3. *Orthoptera*	Earwigs, cockroaches (black beetles), grasshoppers, locusts, crickets, praying mantis, stick and leaf insects.
	4. *Plecoptera*	Stone-flies.
	5. *Isoptera*	White ants, termites.
	6. *Psocoptera*	Book-lice.
	7. *Anoplura*	Sucking and biting lice.
	8. *Ephemeroptera*	May-flies.
	9. *Odonata*	Dragon-flies.
	10. *Thysanoptera*	Thrips.

GROUP OF ECHINODERMS

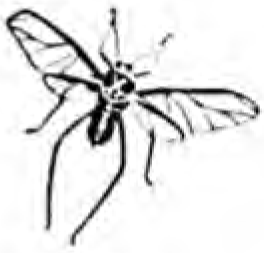
Echinoderms are essentially marine animals and all of them are radial in arrangement, possessing five arms or rays. The underside of a starfisn is covered with hollow tubes ending in suckers, called tube feet, by means of which it crawls along.

11. *Hemiptera*	Bugs, water boatmen, water scorpions, water crickets, leaf hoppers, aphids, green-fly, scale insects, cicadas.
12. *Neuroptera*	Lace-wings, ant-lions, alder flies, scorpion-flies.
13. *Trichoptera*	Caddis-flies and worms.
14. *Lepidoptera*	Butterflies, moths (true caterpillars).
15. *Coleoptera*	Beetles, cockchafers, maybugs, water beetles, devil's coach-horse, ladybirds, stag-beetles, weevils, death-watch beetles, Colorado beetle, dung beetles, tiger beetles.
16. *Hymenoptera*	Bees, wasps, ants, saw-flies, gall-flies, ichneumons, mason bees and wasps.
17. *Diptera*	Flies (two-winged), gnats, midges, bluebottles, house flies, crane-flies or daddy longlegs, hover flies, tsetse fly.
18. *Siphonaptera*	Fleas.


Earwig.


Termite.


Dragon-fly.

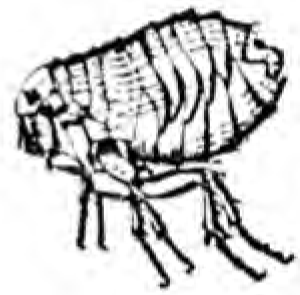

Aphid.


Moth.


Colorado Beetle.


Wasp.


Gnat.


Flea.

PHYLUM VIII. ECHINODERMATA

CLASS A.	**Asteroidea**	Starfish.
CLASS B.	**Ophiuroidea**	Brittle stars.
CLASS C.	**Echinoidea**	Sea-urchins, heart urchins, dollar urchins.
CLASS D.	**Holothuroidea**	Sea-cucumbers.
CLASS E.	**Crinoidea**	Sea-lilies.

PHYLUM IX. PROTOCHORDATA

CLASS A.	**Hemichorda**	(*Balanglossus*).
CLASS B.	**Tunicata**	Sea-squirts and salps.
CLASS C.	**Cephalochorda**	Lancelets.

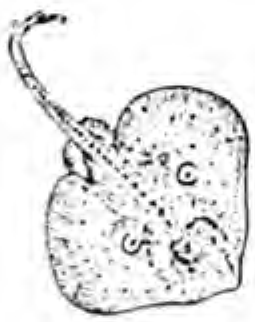

Sea-Squirt.


Lancelet

PHYLUM X. CRANIATA (Vertebrates)

CLASS A.	Cyclostomata	Lampreys, hag-fish.
CLASS B.	Selachii	Sharks, dogfish, nursehounds, skates, rays, sawfish, sting ray, rabbit-fish or king-herring.

Lamprey.

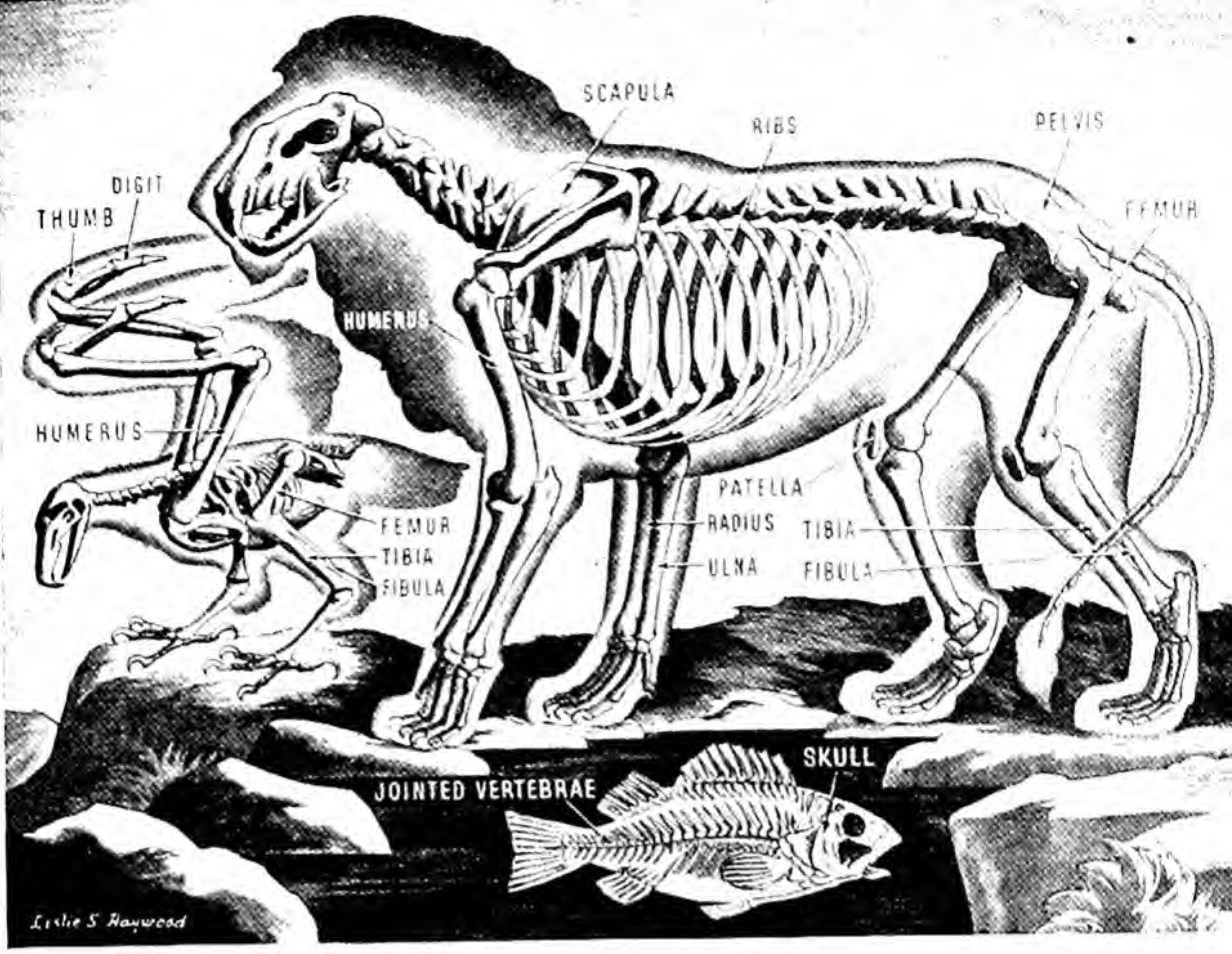


Ray.

CLASS C.	Pisces (Bony fish).	
Sub-Class	1. *Ganoidea*	Sturgeons, gar-pike, bow-fin, bichirs.
	2. *Teleostei*	Salmon, trout, herrings, carp, mackerel, cod, flat-fish, sticklebacks, minnows, eels and all common fresh-water and marine fish.
	3. *Dipnoi*	Lung-fish, mud-fish.
CLASS D.	Amphibia	Newts, salamanders, frogs, toads, blind-eel, hell-bender, axolotl.

EDIBLE FISH OF NORTHERN WATERS

The cod is one of the commonest fish inhabiting northern waters and is found in great quantities off the Dogger Bank and around Iceland and Newfoundland. Two distinguishing features are its large mouth and three dorsal fins. It sometimes attains a considerable size.



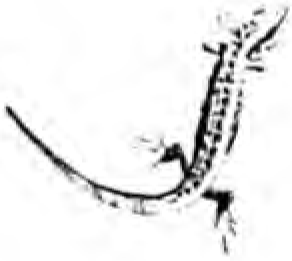
ANIMALS WITH BACKBONES

All animals included in Phylum X, however much their external appearances may differ, are alike in that they all have jointed vertebral columns, or backbones. In all mammals the internal structure is fundamentally the same. Birds and fishes have their bodies adapted respectively to life in the air and life in water.

CLASS E.	**Reptilia**	Crocodiles, alligators, lizards, chameleons, geckoes, skinks, blind-worm, iguanas, monitors, snakes, tortoises, turtles. (Fossil dinosaurs, plesiosaurs, ichthyosaurs, pterodactyls).

Mackerel.

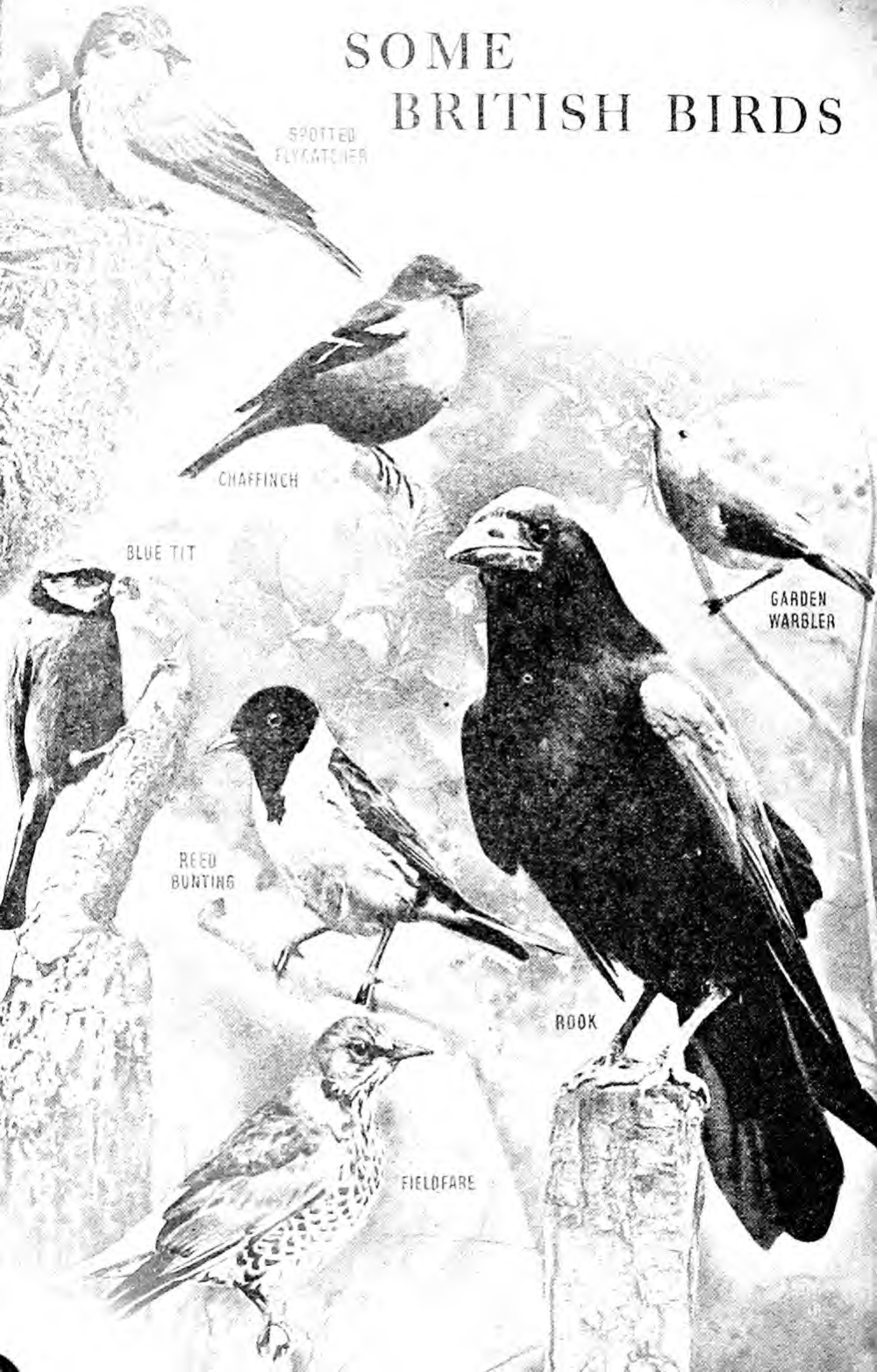
Toad.



Lizard.

CLASS F.	Aves (Birds)		
Sub-Class	1. *Ratitae*		Ostriches, emus, rheas.
Sub-Class	2. *Carinate*		
Legion (a)	Order	1. *Colymbiformes*	Divers, grebes.
	,,	2. *Sphenisciformes*	Penguins.
	,,	3. *Procellariiformes*	Petrels, Mother Carey's chicken, albatross.

SOME BRITISH BIRDS




HEN
STONECHAT
NIGHTINGALE
BLACKBIRD
ROBIN
KINGFISHER
SKYLARK
YOUNG
HOUSE SPARROWS
MISSEL
THRUSH
SONG
THRUSH

RELATIVE OF MAN

Primates is the name given to the highest order of mammals and includes all members of the monkey family as well as man. It was named by Linnaeus and signifies "chiefs." The weeper capuchin monkey has a cowl-like tuft of hair on its crown.

Legion (b)	Order	4. *Ciconiiformes*	Gannets, cormorants, pelicans, herons, storks, bitterns, ibises, egrets, flamingoes.
	,,	5. *Anseriformes*	Screamers, swans, geese, ducks.
	,,	6. *Falconiformes*	Condor, secretary bird, vultures, eagles, falcons, hawks, kestrel, buzzards, harriers, kites.

Penguin.

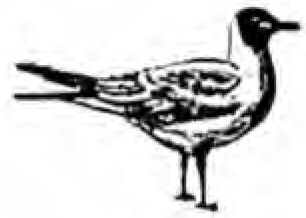
Stork.

Swan.

Legion (c)	,,	7. *Galliformes*	Game birds, fowls, pheasants, partridges, grouse, blackcock, ptarmigan, guinea-fowl, quail, turkeys, curassow, brush turkeys.
	,,	8. *Gruiformes*	Cranes, rails, corncrakes, coot, moorhens, trumpeters.
	,,	9. *Charadriiformes*	Bustards, plovers, sandpipers, woodcock, redshank, curlews, oyster-catchers, stilts, avocets, dunlin, godwits, snipe, pratincoles, stone-curlews, gulls, terns, skuas, guillemots, razorbills, puffins, auks, sand grouse, pigeons, doves.

Pheasant.

Crane.



Gull.

Legion (d)	,,	10. *Opisthocomiformes*	Cuckoos, plantain-eaters, parrots, cockatoos, macaws, lories, budgerigars, parrakeets.
	,,	11. *Coraciiformes*	Rollers, kingfishers, bee-eaters, hoopoes, hornbills, owls, swifts, nightjars, humming-birds, toucans, woodpeckers.
	,,	12. *Passeriformes*	Lyre birds, flycatchers, swallows, martins, shrikes, birds of paradise, bower-birds, nuthatches, tits, tree-creepers, thrushes, blackbirds, robins, nightingales, warblers, whitethroats, wrens, dippers, orioles, starlings, pastors, tanagers, finches, buntings, larks, pipits, wagtails, crows, rooks, ravens, chough, magpies, jays.

Parrot.

Humming-bird.

Lyre Bird.

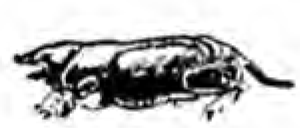
CLASS G. **Mammalia**

Sub-Class	(*a*) *Protheria*	Spiny ant-eater, duck-billed platypus.
	(*b*) *Marsupialia*	Kangaroos, wallabies, koalas, opossums, bandicoots, Tasmanian devils.
	(*c*) *Placentalia*	
ORDERS.	1. *Edentata*	Armadillos, sloths, ant-eaters.
	2. *Insectivora*	Hedgehogs, shrews, moles.
	3. *Chiroptera*	Bats, vampires.
	4. *Rodentia*	Rabbits, hares, rats, mice, voles, lemmings, hamsters, marmots, prairie dogs, gophers, jerbils, jerboas, squirrels, beavers, porcupines, guinea-pigs, agoutis, chinchillas.
	5. *Hyracoidea*	Coneys.
	6. *Proboscidea*	Elephants.
	7. *Sirenia*	Sea-cows (manatee, dugong).

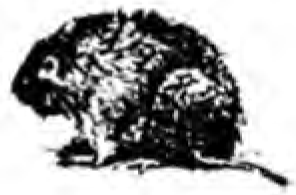

Duck-billed Platypus.

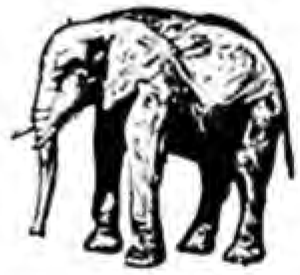

Wallaby


Sloth.


Mole.


Bat.


Vole.

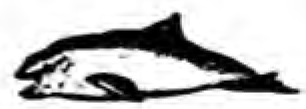

Elephant.


Manatee.

8. *Ungulata*	Tapirs, rhinoceroses, horses, zebras, asses, pigs, chevrotains camels, okapi, giraffes, deer, cattle, bison, buffaloes antelopes, gnus, duikers, gazelles, sheep, goats.
9. *Carnivora*	Cats, lions, tigers, leopards, jaguars, cheetahs, ounces, dogs, foxes, wolves, hyenas, badgers, stoats, weasels, martens, skunks, raccoons, civets, bears, pandas, seals, sea-lions, sea-elephants, walruses.
10. *Cetacea*	Whales, dolphins, porpoises, grampus, killers.
11. *Primates*	Lemurs, monkeys, apes, baboons, marmosets, men.


Antelope.


Lion.


Porpoise.


Monkey.

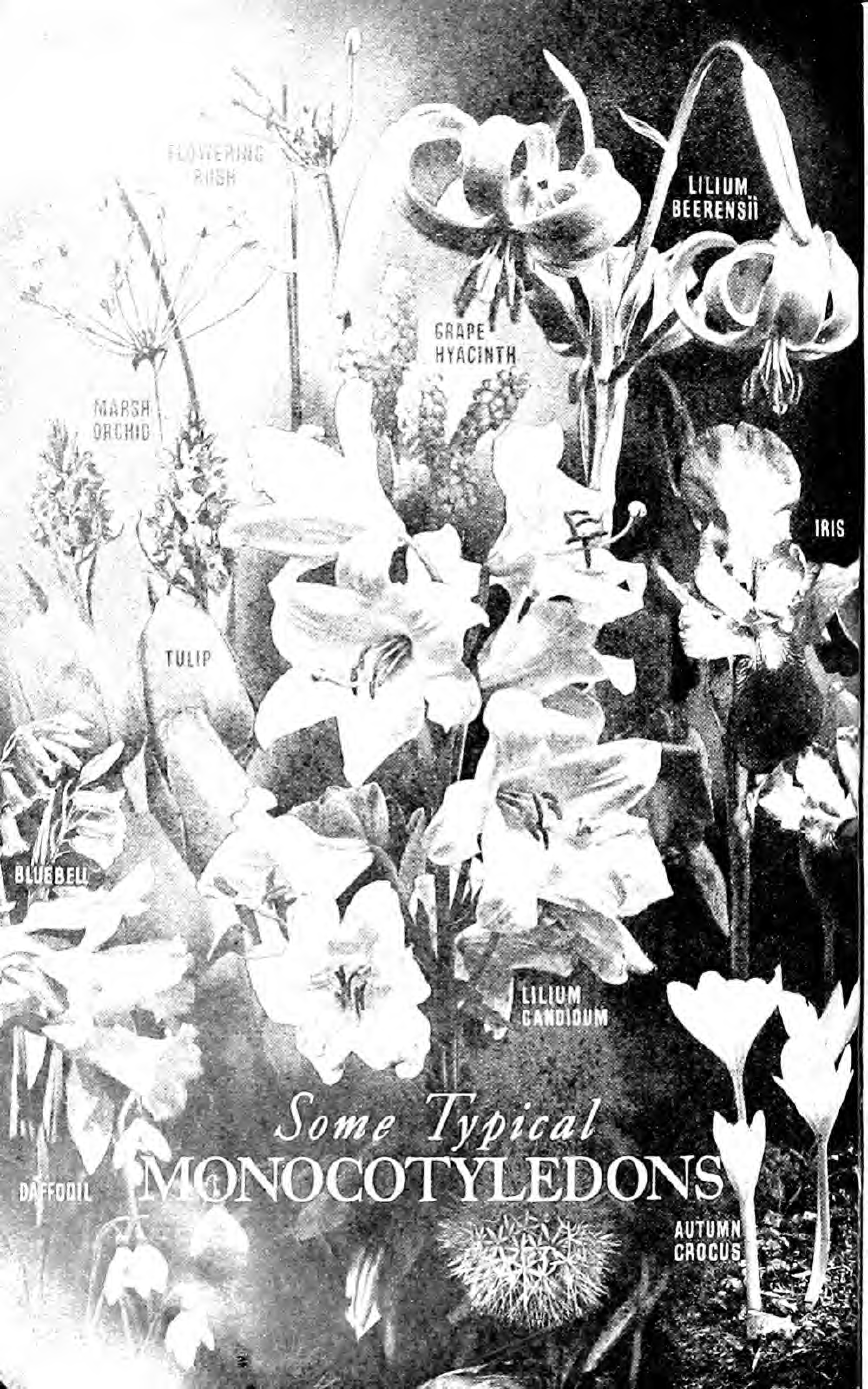
ONE OF THE CARNIVORA

Mexican tigrillo, or wild cat, stalking its prey. The cat family includes some of the larger beasts of prey, like the lion and the tiger, as well as the domestic and other cats. It may be divided into two main groups, one covering animals which roar and the other animals which purr. These groups are subdivided again into numerous species. Carnivorous animals are those which kill and devour living prey.

Test Yourself

1. Why is it necessary to classify animals scientifically and who invented the system of naming animals used today?
2. How many main Phyla are there? Can you name at least one animal from each of these?
3. What is the simplest form of animal life?
4. What characteristics of a sponge justify its inclusion in the animal world? What is its value to other animals and to man?
5. Name four edible molluscs and describe the methods of feeding of one of them.
6. Which of the eleven orders of mammals do you consider covers animals of most importance to man?

Answers will be found at the end of the book.


FLOWERING RUSH
LILIUM BEERENSII
GRAPE HYACINTH
MARSH ORCHID
IRIS
TULIP
BLUEBELL
LILIUM CANDIDUM
Some Typical MONOCOTYLEDONS
DAFFODIL
AUTUMN CROCUS

CHAPTER III

HOW PLANTS ARE CLASSIFIED

Obviously, we cannot all be trained botanists, but if we wish to enjoy to the full some of the wild flowers and other forms of plant-life that attract us by their grace and beauty, we must be able to identify them and know something about the different groups or divisions to which they belong. True, most of the flowers of the British countryside—what are left of them—have old, simple, well-beloved English names; but we shall soon discover, as our interest deepens, that not all of these possess recognized English names. Therefore, some working knowledge of how the different kinds of plants are grouped or classified is a necessity.

Four Main Divisions

The plant world is now usually divided up by botanists into four large main divisions; the members of each division differing very conspicuously from those of the others, beginning with the very simplest known forms and culminating in the highest.

To the first division, called the Thallophyta, belong the algae, forms of freshwater and marine plants, including the seaweeds, which possess no differentiation into roots, stems or leaves; all the different kinds of fungi, the bacteria, moulds and mushrooms; and also those curious composite plants, the lichens, familiar as softly tinted encrustations growing on old walls and damp rocks. All these forms of plant-life are relatively simple in structure, showing no true division into root, stem and leaves, but are composed of simple cellular tissue throughout.

For this reason, the plant-body is known as a thallus (from the Greek *thallos*=a green shoot), no matter what its size or shape. While all the algae possess chlorophyll and are able therefore to utilize the carbon dioxide of the air in just the same way as the higher flowering plants, the fungi, on the other hand, are destitute of chlorophyll, and consequently are obliged to exist either upon living organisms, or upon decaying plant or animal matter.

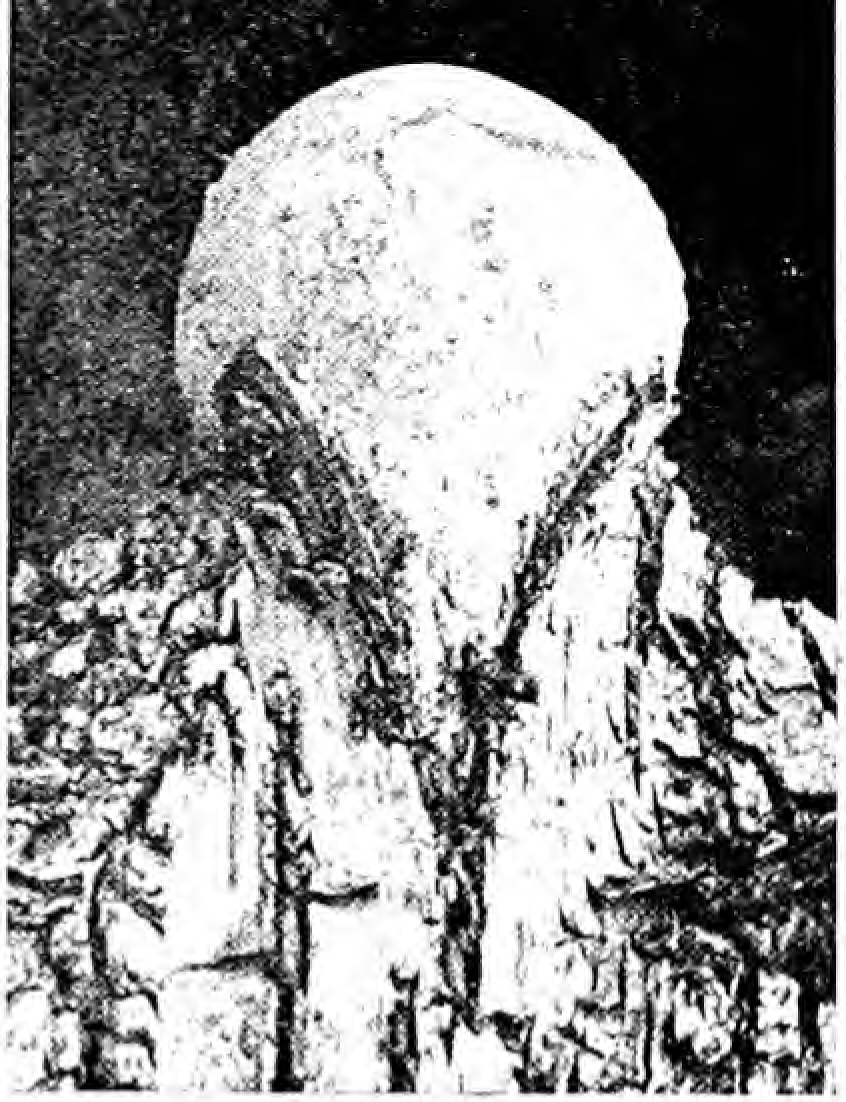
Though some fungi attain to a considerable size, their structure is always relatively simple, their thallus consisting of long threads or hyphae, either free or massed together in various ways. The lichens are composite plants, and actually consist of an alga and a fungus living together in an intimate association or partnership of mutual benefit, known as symbiosis.

In the second great division, known as the Bryophyta, are placed the mosses and liverworts. These plants generally, though not universally, possess a stem bearing leaves, but may have no true roots. To the third division, called the Pteridophyta, belong the ferns, horsetails, and so-called club-mosses. All are plants showing a marked advance on those forms included in the two previous divisions, for they are clearly differentiated into root, stem and leaves and their internal tissues include a great variety of structure. They do not, however, possess conspicuous flowers, nor do they produce seeds.

Definition of Cryptogam

Originally the term cryptogam was applied to all the plants included in these three great divisions, being used to distinguish flowerless plants, in which the process of fertilization was said to be hidden, from flowering plants in which it is easily observed. This distinction, however, really no longer holds good, for thanks to the perfection of the modern microscope, fertilization is as readily observable today in the cryptogams as it always has been in the flowering plants. Nevertheless, the old term is still retained; the Thallophyta and the Bryophyta being classed by botanists as cellular cryptogams, and the Pteridophyta as vascular cryptogams.

The fourth and last great division is known as the Phanerogamia, and contains

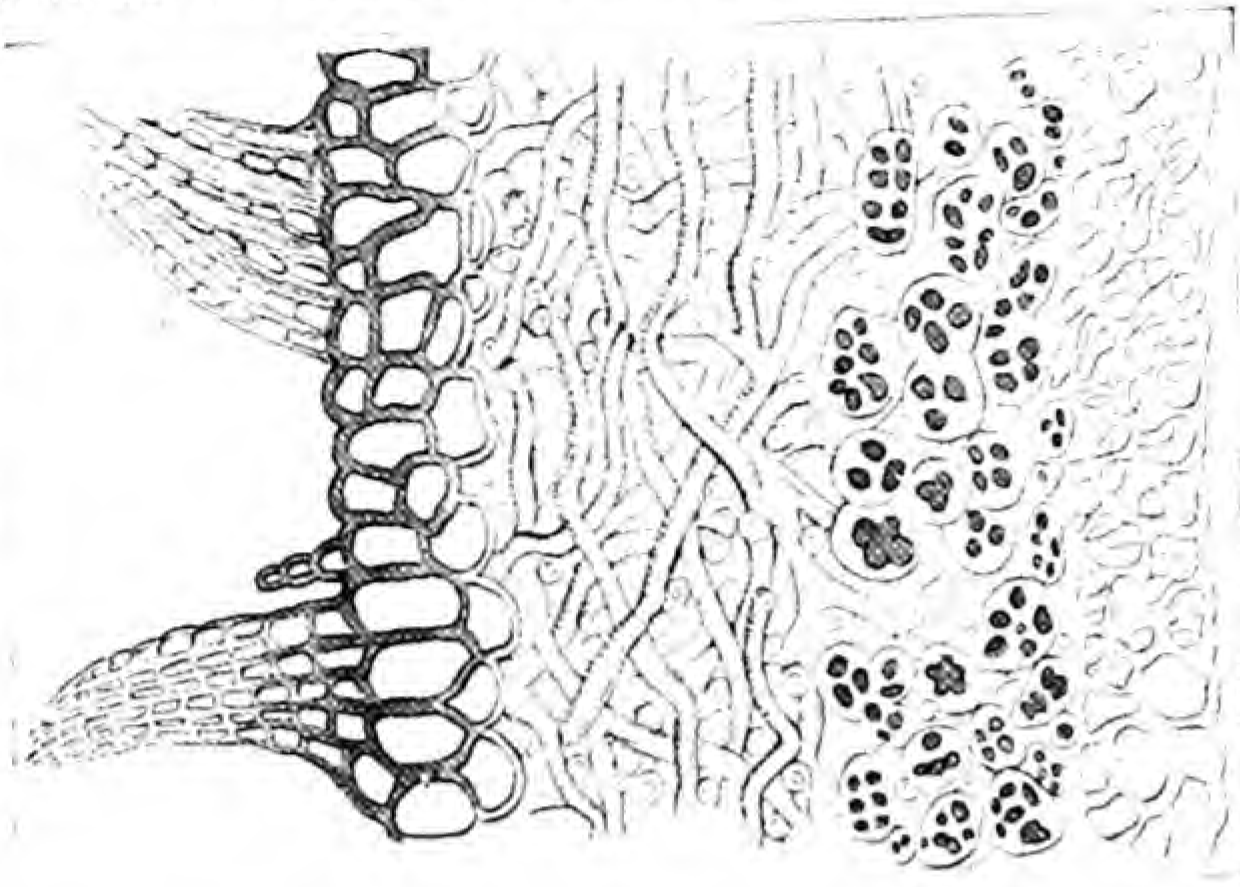


THREE VARIETIES OF BASIDIOMYCETES

Above are two polyporous fungi of different forms and below is the shaggy ink-pot (Coprinus), *a type in which the cap is long, narrow and scaly.*

all the seed-bearing plants; plants distinguished as generally possessing more or less conspicuous flowers which, if development continues unchecked, give rise to fruits in which seeds are formed. The occurrence of the seed is now considered as being the special characteristic of all plants included in this division, and therefore the more modern term Spermatophyta, derived from two Greek words meaning, literally, seed-plants, is often adopted in preference to the old term. Phanerogamia, originally established by the great Linnæus, was used by him to distinguish alone those plants in whose flowers the sexual organs could be easily distinguished, and the process of fertilization readily observed; the term itself, Phanerogamia, being derived from the Greek *phaneros* = manifest; and *gamos* = union.

The Phanerogams are divided into two distinct groups or sub-divisions (subphyla), called respectively (1) the gymnosperms, or plants with naked seeds; plants characterized by the pollen or male cell being brought directly into contact with the ovule or female cell which, after fertilization, develops into the seed; and (2) the angiosperms, plants which have their ovules or seeds enclosed in an ovary or seed-case, and, consequently, in which fertilization has to take place through a special organ called the stigma. The angiosperms are again divided into two classes



CROSS-SECTION OF LICHEN

A plant composed of a green alga and a mould-like fungus living together in symbiosis. The fungus forms a mass of closely-woven colourless threads which surround the green cells of the alga and hold it together. The alga, which has chlorophyll, manufactures food which is shared by the fungus, while the latter provides moisture for both.

(1) the dicotyledons; and (2) the monocotyledons, or plants having only one cotyledon.

The gymnosperms are of special interest because they are known from the geological evidence of their fossil remains to be ages older than the angiosperms, and they retain many characteristics linking them to their more primitive cryptogamic ancestors. In fact, they formed a very conspicuous part of the plant-life of the great carboniferous period, and their fossil

FERNS AND FUNKIA IN WOODLAND SETTING

Aspidium filix-mas, *or male fern (left), is usually found in damp, shady places. It has a short, thick stem called a rhizome and reproduces vegetatively or by spores.*

remains, beautifully preserved, are often found in coal seams. Today their chief representatives are the yews and pine-trees, the ginkgo or maiden-hair tree of Japan, and in the tropics, the cycads.

The principal classes and orders of plants belonging to the four great divisions are for convenient reference set out in the following tabular form :—

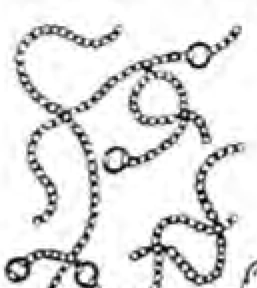
DIVISION I—THALLOPHYTA

This division includes the algae, fungi, and lichens. The algae possess chlorophyll and are therefore capable of assimilating and providing independently for their nutrition. Fungi, on the other hand, being destitute of chlorophyll, lead a parasitic or a saprophytic mode of life. The lichens must be regarded actually as composite forms of plant-life, their thallus affording an instance of an intimate partnership, or symbiosis, between an alga and a fungus.

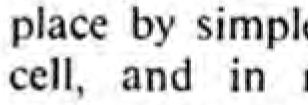

Bacterium

Class I. Bacteria.—Unicellular organisms of very minute size, only visible under the microscope. Each individual consists of a single cell possessing neither chlorophyll nor nucleus; in form either spherical, rod-shaped or spiral. Some at certain stages of development possess delicate protoplasmic cilia rendering them capable of active movement. They abound everywhere, and while many parasitic forms are the cause of devastating and fatal diseases in man, domestic and wild animals and in higher plants, many saprophytic species play an important and very useful part in agriculture and other industries. From their exceedingly simple structure, they are regarded as primitive organisms showing no certain relationship to any other type of plant-life, and therefore are placed in a special class apart from the rest of the true fungi.

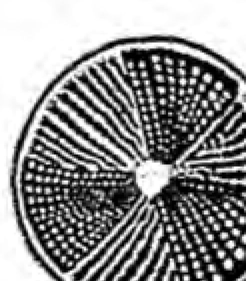
Class II. Cyanophyceae.—The blue-green algae. Small, very simple unicellular or filamentous plants of primitive organization, mostly blue-green in colour, possessing chlorophyll but no true nucleus. As in bacteria, reproduction depends entirely upon the simple division of the individual cell. They consist of single isolated cells or colonies of cells, or form into short filaments. Distributed over the whole earth, appearing as mucilaginous masses, or sheets of fine filaments, occurring in shallow water, or moist earth, and on the bark of trees, or symbiotically in the tissues of higher plants. *Nostoc*, a very common species consisting of gelatinous colonies containing numerous interwoven necklace-like filaments, frequently makes a sudden appearance on damp, muddy paths, after rain.


Algae (Nostoc)

Class III. Flagellata.—Very small unicellular organisms, many of particular interest to the biologist as closely resembling in some ways the simplest unicellular forms, are often termed phytozoa, or plant animals. They are to be found wherever there is water, from puddles and shallow ponds to the open sea, often occurring in such vast numbers as to give to the water an olive or bright green colour. One of the commonest of these flagellates is *Euglena viridis*, to be found in almost any pool of stagnant water throughout the summer; it is a minute, bright green, spindle-shaped organism, which has a single flagellum by means of which it moves through the water. Multiplication takes place by simple division of the individual cell, and in many species thick-walled resting spores are formed, capable of withstanding periods of drought, or which remain dormant in the mud at the bottom of the pond throughout the winter.


Euglena Viridis

Class IV. Diatomaceae.—The diatoms are an immense group of minute unicellular plants which grow in fresh and salt water and upon moist soil. As a rule they occur together in large numbers. Their olive-brown colour is due to a brown pigment, diatomin, which masks the chlorophyll which is also present. Each individual consists of a single cell, the wall of which


Diatom

FIELD OR COMMON HORSETAIL

One of an interesting race of plants which is fast dying out. The photograph shows the branching shoots which follow the early jointed stems ending in a cone from which the plant gets its name. It has a much-branched underground stem or rhizome.

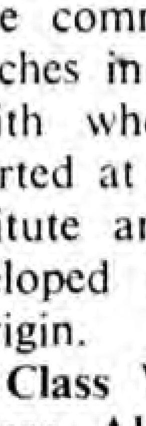
is encrusted with silica. This cell-wall consists of two halves or valves (frustules) which fit into one another like the lid on a pill-box; and the valves, although so minute, are beautifully sculptured, dotted, ribbed, etc.; very popular with microscopists on account of their extraordinary variety of shape and pattern. Over two thousand living species are known, widely distributed over the globe, and their fossil remains form deposits of considerable thickness in various parts of the world.

Class V. Chlorophyceae.—The green algae. Some show a considerable advance in size and structure; occur for the most part floating or attached, in fresh water, moist situations and on the seashore between tidemarks. Two modes of reproduction; asexual by what are termed swarm- or zoospores, which are naked more or less pear-shaped cells with two to four flagella at the pointed end. In the sexual reproduction two cells (gametes) conjugate; the male cells are usually smaller and always flagellated, while the female cells are in some species non-motile egg-cells. As the result of conjugation, a thick-walled resting-cell, or zygote, is formed. A very beautiful colonial form common in ponds during the summer is *Volvox globator*, spherical in shape, bright green in colour, and motile by means of numerous flagella. The desmids rank among the most beautiful of the smaller species and exhibit a great variety of form, cylindrical, or like tiny, green, new moons, biscuit-shaped, or growing in chains; they occur especially on peat-moors where the water has an acid reaction. Many of the *Chlorophyceae* occur as slender green filaments growing in ponds and streams (*Spirogyra, Oedogonium, Ulothrix*), while the unicellular *Pleurococcus vulgaris* forms the familiar bright green powdery layer covering damp tree trunks and wooden palings. The so-called sea-lettuce or green laver (*Ulva latissina*) is very common on rocks on the seashore near high-tide mark, and forms large, green, wavy fronds firmly anchored to the rock. Many species of *Enteromorpha* are abundant

between tide-marks on the seashore, and some grow in fresh water. The thallus forms a bright green, branched hollow tube, the walls of which are only one cell thick.

Class VI. Characeae.—The stoneworts. They grow in ponds and ditches; and in some parts of the Norfolk Broads form extensive growths, the living plants resting on the decomposing remnants of former generations and thus gradually raising the bottom level of the Broad. *Chara fragillis*, the commonest species, is some twelve inches in height, and consists of an axis with whorled, leaf-like appendages inserted at the nodes. The stoneworts constitute an isolated group of highly developed green thallophytes of ancient origin.

Class VII. Phaeophyceae.—The brown algae. Almost all are seaweeds, and owing to their large size and extraordinary abundance are familiar to every visitor to the seaside, and many species exceed both in size and complexity any of the green algae. Their characteristic brown colour is due to the presence of a pigment which masks the green of the chlorophyll. The majority are reproduced by zoospores, and in some species resting spores are produced. *Ectocarpus siliculosus* is a very common and simple species with a filamentous branched thallus. It consists of two parts; a creeping primary portion by which it is attached to the substratum, usually one of the larger seaweeds, and a tuft of branching threads, often several inches in length, arising from the creeping part and waving freely in the water. To the brown algae belong the familiar oar or ribbon-weeds (*Laminaria*), the serrated and bladder wracks (*Fucus*), and the interesting *Sargassum* which grows on the coasts of the West Indies and tropical America, whence it is carried in vast quantities by the ocean currents to that part of the Atlantic known as the Sargasso Sea where it leads a pelagic life.

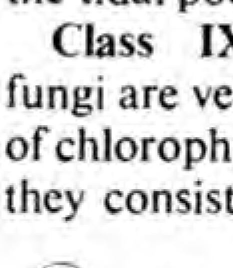


Seaweed.

Class VIII. Rhodophyceae.—The red algae. The majority are seaweeds, though a few belong to fresh waters. Usually red or violet, sometimes dark purple or reddish-brown, the presence of a red, in some species a blue pigment, masks the green of the chlorophyll. The thallus is always multicellular, very diverse in form, fine or coarse filaments, cylindrical or leaf-like. *Delesseria sanguinea*, named after the celebrated French naturalist Delessert, grows in deep rock pools near low-tide mark in the form of delicate rose-red leaf-like fronds. *Rhodomenia palmata* grows in large, purple-red fronds and yields the edible "dulse," once a popular local dish. *Polysiphonia* and *Callithamnion* are slender, branching, filamentous species. To the red algae belong the important coralline seaweeds, so called on account of the carbonate of lime secretions deposited in their cell-membranes, giving them a curious stony appearance; certain species in the tropics contribute largely to the formation of coral reefs. *Corallina officinalis*, a beautiful, pinkish-coloured branching species, is common in the tidal pools around the coasts of Britain.

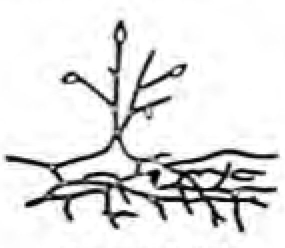
Coralline Seaweed.

Class IX. Myxomycetes.—The slime fungi are very primitive organisms destitute of chlorophyll. In their vegetative condition they consist of naked amoeboid masses of protoplasm known as plasmodia, and are found in tan-pits, on the damp soil in woods, on fallen leaves and in decaying timber, where they creep about exhibiting continued change of form. The plasmodia of the so-called flowers of tan (*Fuligo varians*) reach a very considerable size, while *Plasmodiophora brassicae* attacks the roots of cabbage, causing the disease known as "fingers and toes." Reproduction takes place by means of spores which germinate in water or on a wet substratum. Over four hundred species are known.



Slime Fungi.

Class X. Phycomycetes.—Algal fungi, for the most part very small and leading a parasitic or saprophytic existence. The parasitic species are the cause of



Potato Blight.

PINE CONES

Cone-producing plants or conifers belong to the group known as gymnosperms, plants which produce their seeds naked instead of being enclosed in a case. The ripe cone opens and turns down to disperse the seed.

many widespread diseases among plants, *Phytophthora infestans* being responsible for late blight in potatoes, a serious disease in wet seasons, while *Plasmophora viticola* is the cause of the false mildew of the vine. Both these parasitic fungi were introduced into Europe from America during the nineteenth century, and unhappily have become firmly established. A typical saprophytic species is *Mucor mucedo* which forms the familiar white, fur-like growth on bread, jam, potted meats, dung, etc.

Yeast budding.

Class XI. Eumycetes.—The higher fungi. The Eumycetes are divided into two sub-classes, (1) the Ascomycetes, so termed in reference to the tubular sporangium or ascus which gives rise to the spores; and (2) the Basidiomycetes in which the spore-producing organ is termed the basidium. To the Ascomycetes belong yeasts which occur on fruits and mucilaginous exudations in nature, and give rise to alcoholic fermentation when present in sugar solutions.

The wine-yeast (*Saccharomyces ellipsoideus*) is a natural wild yeast passing the winter in the soil of the vineyards in the form of spores, and reaching the grapes during the following summer. The beer-yeast (*Saccharomyces cerevisiae*), on the other hand, is only known in the cultivated form.

Distinct races of both species occur and are grown in pure laboratory cultures and employed in fermentation. Two well-known moulds, *Aspergillus herbariorum*, and the now famous *Penicillium*, are

TYPICAL ANGIOSPERM

Plant which has its seeds enclosed in an ovary or seed-case. Plants of this group usually have conspicuous coloured or scented flowers. The seed-case of the meadow cranesbill has a long pointed style like a bird's bill.

included among the Ascomycetes, as well as the mildew-fungi (*Erisiphaceae*), which are parasitic in habit causing serious injury to the leaves and fruit of many cultivated plants. *Tuber brumale* and *T. melanosporum* are the valuable edible fungi known as truffles. The second sub-class, the Basidiomycetes, includes an immense number of fungi most varied in size, form and habit, some being parasitic, others saprophytic; while some are prized as being edible, others are highly poisonous. *Merulius lacrymans* is the dry rot fungus which lives in the wood of joists and flooring of houses. The gill-fungi (*Agaricaceae*) include the edible mushroom (*Psalliota campestris*), and the familiar bright red and green poisonous toadstools *Amanita muscari*, *A. phalloides*, the former popularly known as the fly-agaric.

The *Polyporacea* are parasitic on deciduous trees, the so-called touch-wood fungus (*Fomes formentarius*) being a familiar example, forming large, bracket-shaped, perennial fructifications growing on tree trunks. The rust and the smut fungi are parasitic on cereals and other plants, on which they are the cause of serious diseases; thus the rust fungus (*Puccinia graminis*) causes great harm to winter wheat, and three species of smut-fungi (*Ustilago*) attack the ovaries of wheat, barley and oats.

Iceland Moss

Class XII. Lichens.—The lichens are composite plants, the plant body or thallus consisting of fungal hyphae and algae; the algae occurring may be either unicellular or filamentous species, while the fungi are chiefly Ascomycetes. In the simplest forms, the fungus grows in the mucilaginous walls of the alga, or the fungal hyphae grow as threads around the individual filaments of the alga; while in others, the fungal and algal constituents of the lichen form stratified layers in the building up of the thallus. Some species form the familiar orange and red incrustations adhering closely to rocks and old stone walls, others possess a leaf-like form, of which the so-called Iceland moss (*Cetraria islandiea*) and the reindeer moss (*Cladonia rangiferina*), are familiar examples, while the beard lichen (*Usnea barbata*), frequently to be found growing on the trunks of trees, is a branching form.

DIVISION II—BRYOPHYTA

The Bryophyta known as cellular cryptogams comprise two classes of plants, (1) the liverworts (*Hepaticae*), and (2) the mosses (*Musci*). They are distinguished from the Thallophyta by the structure of their sexual organs, termed antheridia and archegonia.

Liverwort.

Class I. Hepaticae.—Most of the liverworts inhabit moist situations and some tropical species are true epiphytes growing on the stems and leaves of the forest trees. Two leaf-like species to be found growing on damp soil, on the sides of ditches, water courses and similar situations, are *Marchantia polymorpha*, and *Pellia epiphylla*. The latter is perhaps the commoner species, and in its vegetative condition consists of a green, flat, lobed thallus, repeatedly branched. It grows in communities often collectively covering a considerable patch of ground. The upper surface of the rather leaf-like thallus is dark green with what looks like a central midrib. On the underside numerous root-hairs grow out from the midrib and serve to anchor the plant in the soil. The liverworts, like other Bryophyta, possess no true roots.

Bog Moss.

Class II. Musci.—The true mosses are widely distributed geographically and are to be found growing in the most varied situations, on tree trunks, on rocks and walls, on moors, in swamps and on dry woodland soil. *Funaria hygrometrica* is a very common easily recognized species, usually growing on the ground in close tufts of a bright green colour. The bog mosses (Sphagnaceae) grow on swampy moorland where they form large tussocks

TREE FERNS IN AN AUSTRALIAN FOREST

Under tropical conditions ferns flourish and attain sizes unknown in temperate countries. The tree fern is found mostly in Australia and New Zealand. It has a tall cylindrical stem sixty feet or more in height, with a crown of spreading fronds.


Some Typical
DICOTYLEDONS
LIVE-
LONG
GORSE
BLACK
MULLEIN
PURPLE
LOOSESTRIFE
FOX-
GLOVE
MARGUERITE
PETUNIA


CHERRY
WILD ROSE
BELL HEATHER
POLYANTHUS
NETTLE
SCABIOUS
GOLDEN ROD
GERANIUM
ASTER
CANTERBURY BELL

saturated with water. The upper parts of the stems continue their growth from year to year, while the lower portions die away and become converted into peat.

DIVISION III—PTERIDOPHYTA

This division includes the ferns, horsetails and club mosses, the most highly developed or vascular cryptogams. The fossil remains of many extinct species are abundant in strata of the carboniferous period.

Class I. Lycopodiinae.—The club-mosses. One of the commonest of the British club-mosses is *Lycopodium clavatum*, which is found growing on heaths and hilly ground. It has a hard, creeping stem, often one or two feet in length, with ascending forked branches covered completely with crowded moss-like leaves. The common selaginella, or lesser club-moss (*Selaginella selaginoides*), has slender, prostrate, much-branched stems, forming moss-like patches three or four inches in diameter, growing in moist, stony or boggy situations. *Selaginella kraussiana*, a native of South Africa, is a common species now generally cultivated in greenhouses for its graceful, pale green, creeping stem.


Club Moss.

Class II. Equisetaceae.—The horsetails are an ancient and interesting race of plants, of which some ten species inhabit Britain, growing in fields and moist waste ground, in marshes and damp woodland. The field ,or common horsetail (*Equisetum arvense*) is a typical species. Deep down beneath the surface of the ground the plant has a much-branched underground stem or rhizome, from which the aerial stems are sent up. The stems and branches are jointed with whorls of little developed leaves, each whorl being united to form a sheath, giving to the whole plant a curiously stiff and formal appearance. The stems above ground in this species are of two kinds. First, in early spring, unbranched fertile shoots are sent up, each terminating in a cone bearing the sporangium. Later the sterile, branching shoots appear, which are a deep green colour, for they constitute the assimilating apparatus for the plant.


Horsetails.

Class III. Filicinae.—The ferns are a vast

FLOWERS OF A GYMNOSPERM

Branch of Austrian pine, showing the two types of cone, in the centre the female, seed-producing cone surrounded by the male cones which produce pollen.

group of plants, greatly outnumbering in genera and species all the other Pteridophyta, varying in size from the magnificent tree ferns of the tropics and Australia and New Zealand, to the delicate little filmy ferns hardly larger than the mosses. Of our native species, typical and familiar to most people as to call for no detailed description are the common bracken (*Pteris aquilina*), the hart's tongue (*Scolopendrium vulgare*), the male fern (*Aspidium filix-mas*) and the common polypody (*Polypodium vulgare*).

Hart's Tongue.

DIVISION IV—PHANEROGAMIA (SPERMATOPHYTA)

Sub-division I. Gymnospermae.—Includes the cycads, the ginkgo or so-called maiden-hair tree, and the Coniferae—the yews and various species of pine trees. The cycads are restricted to the tropics. *Cycas revoluta*, one of the best known, is a native of Asia and has a thick woody stem crowned by a mass of large, pinnate, foliage leaves. The maiden-hair tree (*Ginkgo biloba*), is a native of China, but is often to be seen in cultivation in Britain. Both *Ginkgo biloba* and *Cycas revoluta* are of special interest and unique, in that they demonstrate the transition in the methods of fertilization between cryptogamic and phanerogamic plants. No such clearly defined transition, however, has so far been discovered to bridge the gulf between the gymnosperms and the angiosperms. The yew (*Taxus baccata*), the Scotch pine (*Pinus sylvestris*), and the juniper (*Juniperus communis*), are familiar British examples of the Coniferae.

Juniper Tree.

Buttercup.

Sub-division II. Angiospermae. — Plants distinguished from the gymnosperms by having their seeds or ovules enclosed in an ovary or seed-case, and possessing more or less conspicuous flowers; divided into two classes, based on the number of seed-leaves or cotyledons.

Wild Rose.

Class I. Dicotyledons, plants with two cotyledons. Familar British examples: the Buttercup family, the Rose family, the Compositae (daisy, dandelion, thistle, coltsfoot, goldenrod, etc.), the Convolvulus family, the Heath family, and among the trees, the elm, alder, birch, beech, the oak, willow and the poplar.

Crocus.

To **Class II,** Monocotyledons, belong the orchids, iris, crocus, daffodil, snowdrop, solomon's-seal, lily of the valley, butcher's broom, fritillary, bluebell (scilla), garlic, leek, onion, meadow saffron, the rushes, and all the members of the Grass tribe.

Test Yourself

1. Give the name of each of the four main divisions of the plant world, and mention the kind of plants that belong to each.
2. Give the name of at least one plant from each of the twelve classes included in Division I.
3. Outline the chief distinction from each other between the classes of plants in Division II, and in what way they differ from plants belonging to Division I.
4. Give examples of plants belonging to the three classes of Division III, and how they differ from plants belonging to Divisions I, II and IV.
5. In what way do the plants belonging to the two chief sub-divisions of the flowering plants (Division IV) differ? Give examples of one or more plants typical of each sub-division.

Answers will be found at the end of the book.

GIANTS OF THE FOREST

Sequoias, or giant redwood trees, in a Californian forest. These trees attain an enormous size, often exceeding three hundred feet in height, while the trunk may be as much as thirty feet in diameter. The tree gets its name from its red bark.

CHAPTER IV

THE LIVING PLANT, ITS STRUCTURE AND HOW IT FUNCTIONS

In the plant world we shall meet with great variety in structure, size, shape, and habit; but it is in size, perhaps, that the differences are most striking, ranging from the tiny bacterium visible only through the microscope, to the giant redwood trees of California. The simplest plant consists of a single cell; the giant redwood is built up of millions of such cells grouped together and modified to carry out their various special functions.

Between the two extremes in size, there are many grades of complexity of form and structure, but all alike possess one feature in common, the living cell, or unit of life. Whatever the ultimate size of the plant, it originated as a single cell, and from that primary cell all the others, no matter what their size, shape, position or function may be, have been derived, and it is out of masses of these cells that the roots, stem, branches, leaves and flowers of the plant are developed.

This building up process is not really so very complicated, remarkable though it well may be in its final results, for it depends entirely upon the successful division of the cell into two. Each individual cell at its first formation has the power of dividing into two, and it is by such repeated division that all masses of cells are built up. In those parts of a plant where active growth is taking place, like the growing points of stems and branches, developing buds and the tips of roots, the process is going on with very great rapidity, the new cells dividing again and again, soon after their formation. But the cells do not retain this power of division indefinitely, for as they grow older and larger, they gradually change both their shape and constitution in various ways.

It is these tiny chambers or cells which make up the whole substance of almost all plants, and they are nearly always so small as to be indistinguishable without the help of a microscope. Few measure as much as the one-hundredth of an inch in diameter—that is about half the size of a full-stop in ordinary print—while many measure far less than the one-thousandth of an inch in size. If we cut a very thin slice across any plant stem or leaf-stalk, and placing it on a flat piece of glass, hold it up to the light, we can see with the help of a good pocket lens magnifying not less than twelve diameters, that it is divided up into a number of very minute areas by well-defined lines, that show up as a delicate network. Each of these small areas is a cell, and the network of lines is the cell walls. So far, so good, but what are these cell walls made of, and what does each cell contain?

Composition of the Cell

Well, in a living plant cell we can distinguish the cell wall, which is mainly composed of a substance called cellulose; and within, the tiny cell filled with a very transparent granular material, the living matter, or protoplasm, as it is called, upon which the life of the whole plant depends. Moreover, the protoplasm within each cell contains in some portion of its substance a roundish denser body, a very important structure known as the nucleus.

The nucleus is really a specially differentiated portion of the protoplasm, and, in addition, contains one or more rounded masses called nucleoli. It is intimately associated with the growth and development of the living cell, and though very minute in size, is a very complex and active body. In addition to the nucleus, and more easily distinguished in mature cells, one or more perfectly transparent spots may be seen, cavities in the mass of the protoplasm known as vacuoles, filled with clear fluid.

The contents of the living plant cell are not in a state of rest or immobility. If

with the aid of a microscope we were to examine closely the granular layer of protoplasm, we should be able to see that the granules are moving slowly round the walls of the cell, or where strands of protoplasm cross a vacuole, that the granules pass along them in different directions, flowing towards and then away from the place in which the nucleus is situated. These two movements within the living cell are known as rotation; and, as we watch the circulation of these granules passing along the delicate strands of protoplasm, to and from the nucleus, we cannot fail to notice how close is the resemblance, in miniature, to the unceasing flow of the blood corpuscles to and from the human heart.

Moreover, the little mass of protoplasm living within each cell, although apparently independent and separated entirely from its neighbours by the walls of the cell, is not really so completely isolated, for extremely delicate threads of protoplasm pass through the minute chinks in the walls, uniting the neighbouring cells one with another, so that all are connected, and the living substance throughout the plant is, in fact, practically in direct communication. Each cell is a minute centre of active life, while the growth of the plant as a whole is the result of the combined work of the component cells thus linked together.

Nucleus Divides

The first obvious changes in a dividing cell take place in the nucleus, and are of a very complex character, the ultimate result being that it becomes divided into two exactly equal parts, or daughter-nuclei, as they are termed. Indeed, so fine and accurate is the division, that every minute part of the parent nucleus is split into two identical halves, one half entering into the composition of each of the daughter-nuclei, which, as their mass contracts, gradually separate from each other.

A new cell wall is meantime being secreted by the protoplasm, usually at right angles to, and midway between the daughter-nuclei, so that in a short time they are entirely separated from each other; each becoming completely contained within its cell. It is by this process of repeated cell division that the tissues of the plant are built up. The cell wall is always formed by the living protoplasm, and when first secreted, and before it has undergone any chemical change, is chiefly composed of cellulose, a material formed by the protoplasm from a combination, in certain proportions, of carbon, hydrogen, and oxygen; one of those complex substances known to the chemist as a carbohydrate.

At first, the young cell wall is capable of absorbing water from the outside and retaining it in its substance, it is transparent, dilatable and elastic. This power of absorption and retention of fluid is a very valuable property for some of the processes involved in the normal life of the plant. Very soon after being formed, however, the cell wall tends to thicken by additional layers of cellulose secreted by the protoplasm in contact with it.

Cell Sap

As the cell increases in size and age, the tendency is for the translucent spaces, or vacuoles, either to increase in number, or by coalescence to increase in size. As we have seen, they are not empty spaces in the protoplasm, but are filled with a watery fluid, cell sap, in which various organic and inorganic substances—acids, sugars, nitrogenous compounds and mineral salts—are held in solution. The protoplasm no longer fills the greater part of the cell, but has become reduced to a thin layer, in which the nucleus is embedded, lining the cell wall.

What has happened is that the protoplasm has not kept pace with the growth of the cell, having been used up in adding to the cell wall, and for other purposes, faster than it could be renewed by taking in food. Some cells eventually lose their protoplasm entirely, and then they are incapable of further growth. However, they are still useful to the plant, serving as temporary storerooms, or passages for the circulation of sap, while their thickened walls act as a mechanical support.

Soon after a mass of cells has been formed by repeated division, some of them may become partially separated, so that

SKELETON LEAF
Leaf from which the soft parts have perished, showing the fine network of veins forming the vascular system.

passages or spaces begin to appear, first at the angles where three or four cells meet together, and gradually extending among the mass until every cell abuts upon one or more of them. Groups of cells at the same time become modified in various ways, according to the work which they will have to perform for the well-being of the plant as a whole. Such modified groups of cells form the various tissues of which the plant is built up. Some known as conducting tissues serve as pipe-lines by which fluids are distributed to every part of the plant. Others act as secreting tissues in whose cells oils, gums, latex, etc., are produced; while others again form into protective tissues such as the skin of an apple, the shell of the hazel nut, cork and bark. Moreover, the shapes and sizes of these special cells vary, and their walls show many modifications of structure, brought about by the unequal deposition of the sheets of cellulose and other substances, of which they are formed.

Grouping of Cells

Having ascertained how the masses of cells that constitute the living plant as a whole are formed, let us turn our attention to the way in which they are grouped in the formation of the different tissues in the body of the plant. We shall find that the different kinds of cells are not distributed uniformly throughout, but have a very definite arrangement; the various kinds of cells being associated together so as to form more or less sharply defined layers or strands. Such an association of similar cells is termed a tissue.

During the autumn and winter we may often find a plant stem, such as an old cabbage stalk, in which all the soft parts have perished, and nothing remains but a network of hard, woody, interlacing strings—any so-called skeleton leaf shows the same condition. These remaining strands are known as vascular bundles, and constitute one of the tissue systems of which all the higher forms of plant life are composed. Their all-important function is to serve as conducting channels through which the various food materials pass. In addition, in most cases, they also serve the equally important duty of forming the main supporting skeleton of the plant.

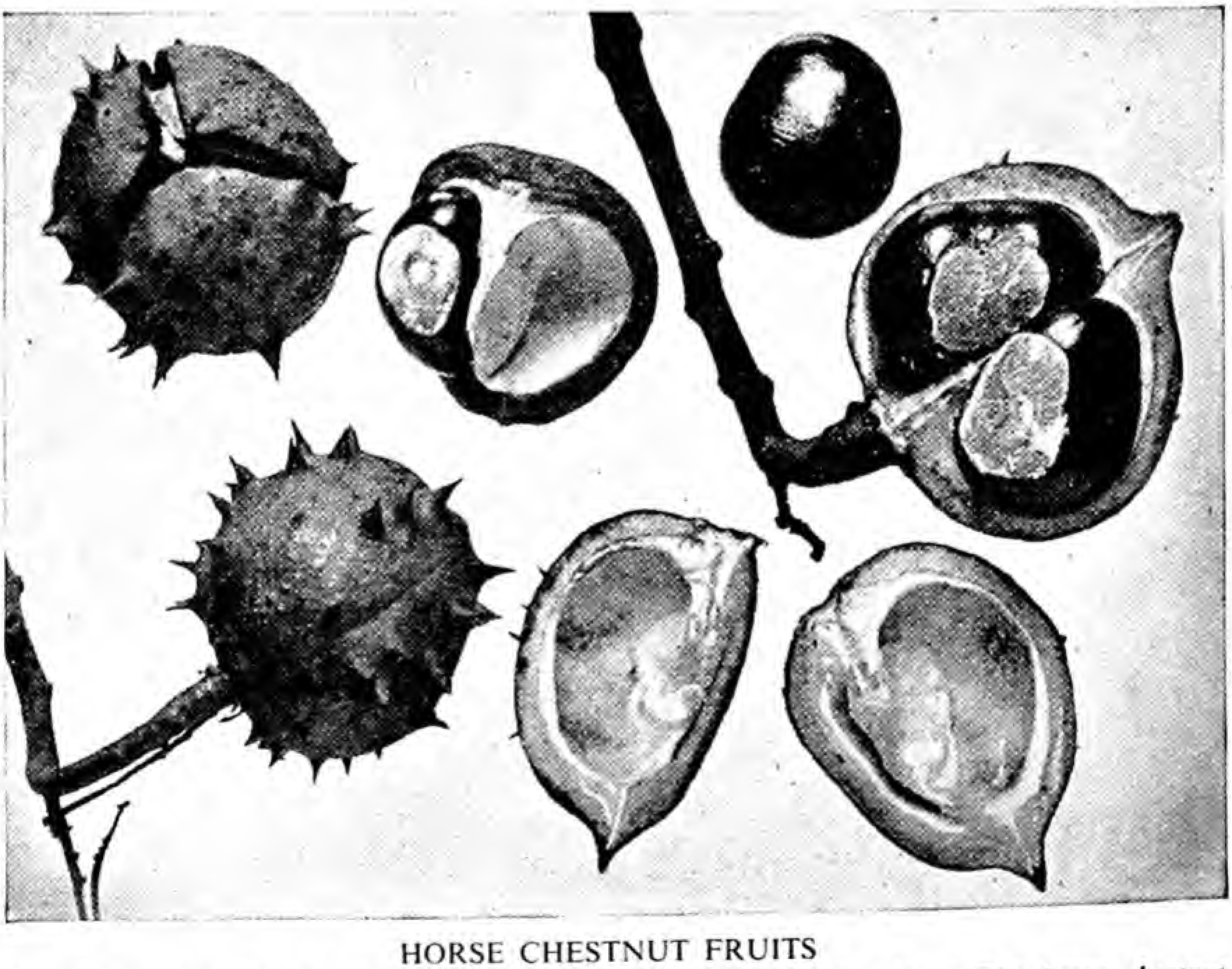
Because it is a familiar plant to be found growing in most gardens, or easily obtained, let us take the common wallflower as our specimen for a study of the tissues.

Its stem, with the exception of the stringy vascular bundles, is soft and succulent, and we shall find that a part of the soft tissue lies to the inside and between the vascular bundles.

These bundles together with the tissue that lies between and within them form what is known as the central cylinder, while the tissue lying on the outside of the vascular bundles is called the cortex. As we hold the entire plant in our hand, we can see that the surface of the upper and younger part of the stem is covered by a very thin skin, easily peeled off with a pocket-knife, when it shows as a colourless transparent membrane which, in spite of its delicacy, is, nevertheless, fairly tough and elastic.

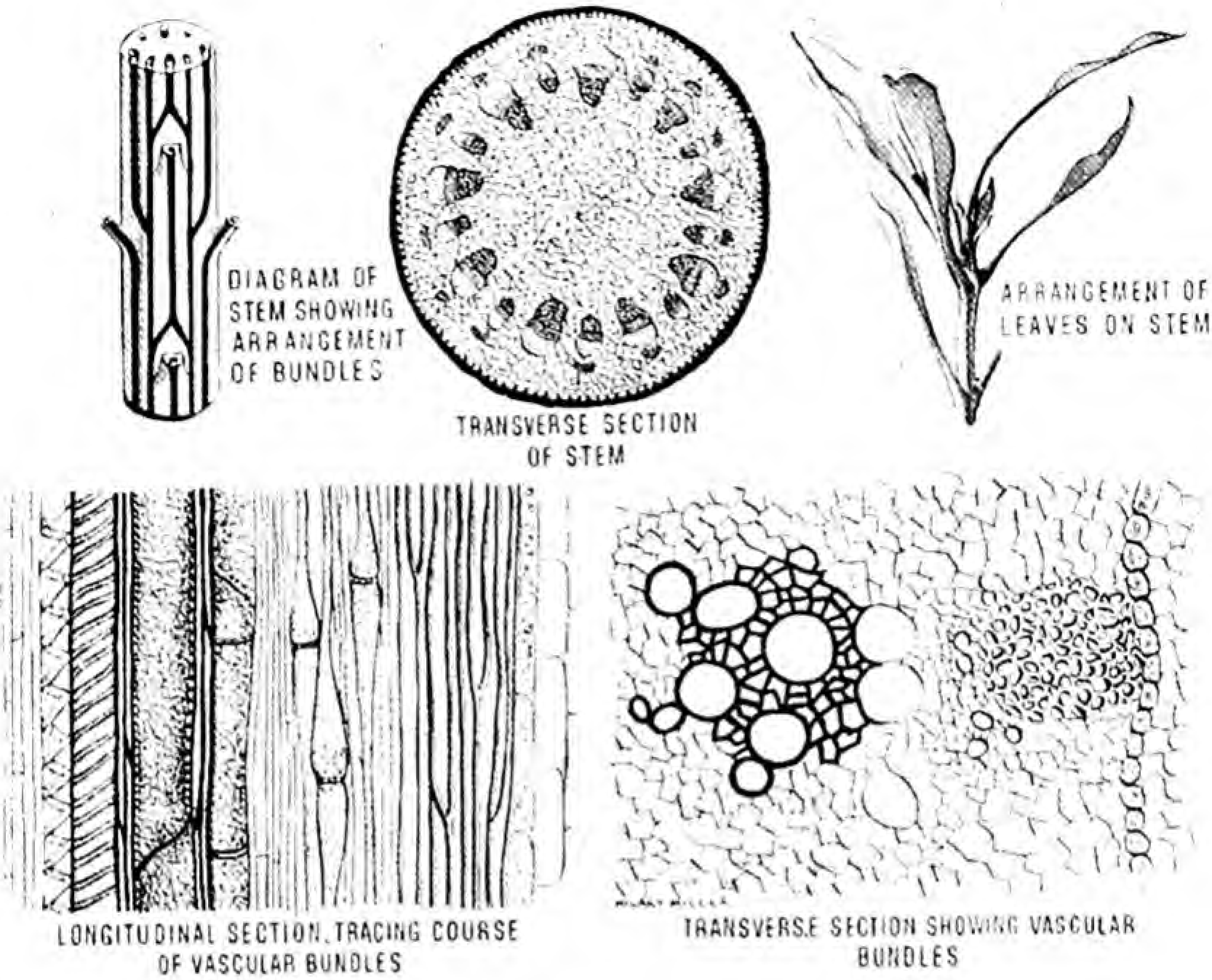
It is confined to the younger parts of the stem, and is known as the epidermis. We shall find the same type of tissue covering the stalks and leaves. The lower and older parts of the stem, on the other hand, are covered and protected by a much thicker and harder skin, the bark; and all such protective tissues, including both epidermis and bark, are included under the general name of dermal tissues.

Now, it is quite possible with the help of such simple tools as a good pocket lens magnifying twelve diameters, and an old discarded safety-razor blade, to make out quite a lot more concerning the structure of the stem of our wallflower. Let us cut a few very thin slices right across the stem and place them on a piece of glass. If we then hold one of these stem sections up to the light, and take a look at it through the lens, we shall be able to see that the cut ends of the vascular bundles are arranged at very regular intervals in a ring, and that the space within the ring is occupied by a large-celled tissue, known as the central pith; while a similar tissue, constituting



HORSE CHESTNUT FRUITS

Plants have cells which become specialized to perform certain functions. The horse chestnut has developed a tough, prickly fruit (or pericarp) of protective tissue to protect the seeds—the nuts—within. When the nuts are ripe the pericarp splits open.



STEM OF THE WALLFLOWER PLANT

Drawings of the stem of the wallflower plant in section. The small diagram on the left (top) shows how the arrangement of the vascular bundles resembles a system of pipe-lines. On the right (bottom) is a close-up transverse view of a vascular bundle.

what is known as the medullary rays, extends between the bundles as far as the cortex which surrounds them.

The vascular bundles, medullary rays and pith, collectively form what is known as the central cylinder of the stem, which is surrounded on the outside by a band of large-celled cortex tissue, and this again by the cells forming the skin or epidermis, which may consist of only a single layer of cells in the more recently formed part of the stem. We are able at once to distinguish many of the cells making up part of a vascular bundle, because of their larger size and thickened cell-walls which give them a very striking and characteristic aspect.

Actually, the bundle is made up of two quite different kinds of tissue. The inner half, which lies towards the centre of the stem, consists chiefly of these conspicuous, rather large cells with thickened, woody walls, and forming the wood or xylem; while the outer part of the bundle, lying towards the cortex, consists of much smaller cells, with thin walls of pure cellulose, and abundant protoplasmic content. This outer part of the bundle is known as the bast or phloem.

Cambium Tissue

Finally, though hardly to be detected with our pocket lens, except perhaps as a narrow streak showing between the woody cells and the bast, there exists a band of small and very regular cells, having very thin walls, showing that active cell-division is taking place. This layer of cells forms what is known as the cambium

ROOTS AND STEMS

Roots can be modified to perform other functions than the normal ones of anchoring the plant and drawing up moisture. Some act as storehouses of food, as in tap roots and root tubers. Stems also become modified for purposes of food storage as in the potato or crocus. Rhizomes are stems which grow horizontally beneath the soil sending up shoots above and roots below. Cladodes are flattened leaf-like stems.

tissue, and is constantly undergoing cell-division, thus adding new cells to the wood internally, and to the bast externally.

So far we have seen enough with the help of our pocket lens to realize that the vascular bundle is made up of three very distinctive sets of tissues; the thick-walled wood cells and the thin-walled bast cells, and the actively dividing, intermediate strip of cambium tissue. Now let us turn our attention to the course of these various tissues within the stem, and also find out something about the functions they perform.

The vascular tissue is generally collected into strands or strings consisting of the vascular bundles, and runs throughout the entire plant, from the roots to the leaves; the strands in the leaves being known as veins. In fact, the arrangement of this tissue is adapted so as to facilitate communication in every direction between leaf, stem and root; and as the bundles are united to one another, it is made easy for the food substances which they conduct, to pass into one or other of the leaves, or to continue their course straight up the stem. Equally, on the other hand, those substances which are formed in the leaves have ready access through the stem bundles to all parts of the plant.

Arrangement in the Stem

To trace the course of these vascular bundles, it is best to follow a bundle from above downwards, as seen in a longitudinal slice or section of the stem, when examined under a microscope. It can then be seen that the bundle enters the stem from the midrib of the leaf and after running inwards for a short distance, turns straight downwards. Continuing its descending course, it reaches a point in the stem where the next leaf, vertically below that from which it started, originated, and joins on to its bundle. In the case of our wallflower stem, besides the principal leaf-bundle which we are tracing, two smaller lateral bundles enter the stem from each leaf, and behave in the same way. The number is not always exact, however, for the smaller bundles may branch or unite together by cross branches. However, at the insertion of each leaf the various bundles are connected together, and thus the whole bundle-system of the stem is built up of these leaf-trace bundles, the upper ends of which run out into the leaves themselves. Where an axillary branch is given off, its leaf-trace bundles are continuous with those of the main stem.

Vessels of Vascular Bundles

As we have already seen in cross-section, the vascular bundle is made up of three elements, namely, cells of relatively large diameter and thickened walls, constituting the wood or xylem; small cells, slightly oblong in cross-section, with thin walls, forming the active cambium and, lastly, the soft-walled cells forming the bast or phloem portion of the bundle. Let us now consider these three elements in closer detail. We shall find that the cells making up both the wood and the bast portion of the vascular bundle have undergone considerable modification, and have coalesced to form the long strands, the vessels as they are termed, of which the vascular bundle consists.

First, let us examine the vessels making up the wood or xylem portion of the bundle. These consist of long, continuous tubes extending through the plant for considerable distances without interruption. Each of these vessels consisted at first of a whole row of superposed cells, each cell with its own protoplasm and nucleus. Then the cross walls separating these cells, one from another, were dissolved away, so that the whole row became converted into one long tube; while the whole of the protoplasm was used up in the process of thickening the walls of the vessel. So when fully formed, the vessel has become a hollow tube which henceforth will simply serve for the conveyance of fluid.

Unequal Thickening

The walls of these vessels have peculiar markings on their inner surface, spirals, single rings, or pits as the case may be, due to unequal thickening, some parts of the wall having increased considerably in thickness, while other parts remained quite thin. The innermost vessels, on account of

their spiral thickening, resemble lengths of garden hose with a spiral wire coiled inside to prevent collapse when empty. The reason for this is that these innermost vessels are the first to be formed, and their walls become thickened before the tissues have ceased to grow in length.

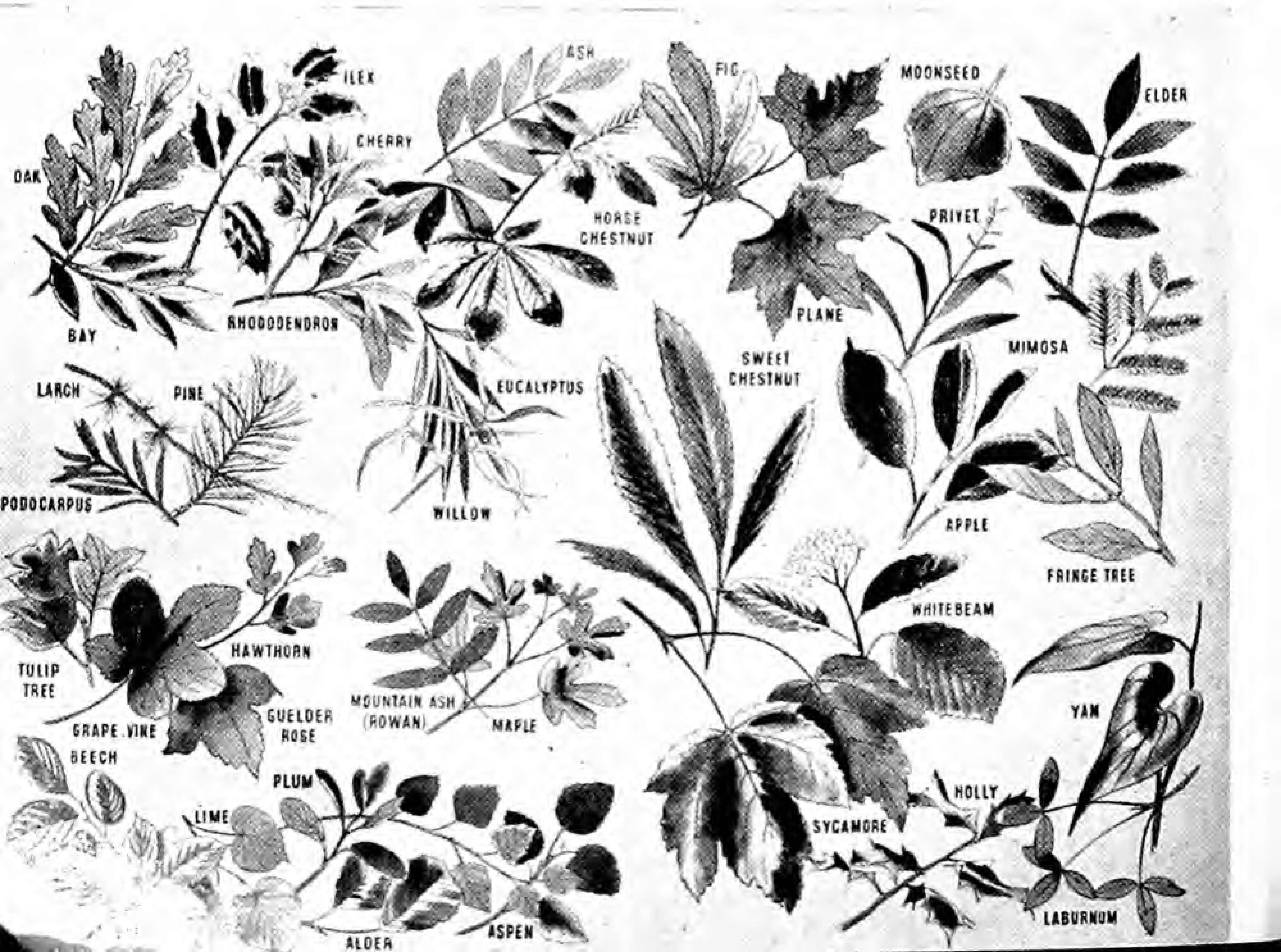
Instead of the spiral thread, we shall in some cases find isolated rings at intervals round the walls of the vessel. Here again, subsequent growth in length has taken place, and as the vessel has increased in length, the rings have been pulled farther and farther apart. We shall find that the vessels a little nearer the outside of the xylem, though still spirally thickened, have the coils of the spiral wound closer together; for in their case, the thickening having been developed later, there has not been so much stretching out by subsequent growth in length. Next to these we shall find vessels in which the uneven thickening on the walls forms a network in which the meshes are occupied by a thin membrane. These are known as reticulated vessels, and are incapable of longitudinal extension, being developed only after the growth of the stem has been completed in length.

In the outer and later-formed parts of the wood or xylem, we come upon vessels in which the walls, though generally thickened throughout, have a number of little oval spaces left therein. These are what are known as pitted vessels; the thin, oval parts of the walls being the pits which permit the passage of fluids from one vessel to another. The various kinds of wall-thickening described above strengthen the vessel and enable it to resist pressure.

We shall find that the wood or xylem portion of the bundle also contains what are known as fibrous cells, which are scattered among the vessels described above and are more common in the later-formed parts of the wood. They are very long, thick-walled cells having sharply pointed ends, and

TYPES OF FOLIAGE LEAVES

Leaves have been given various names to describe their position on branch and stem. Those arranged alternately on the stem, like the apple, are called alternate. Palmate leaves radiate from a centre, as in horse chestnut, and a pinnate leaf is like a feather.



PUMPKIN TENDRILS

Tendrils may be parts of the plant, such as stem or leaves, modified for a special purpose. The tip of a tendril will attach itself to any convenient support and then curl up spirally to establish a firm grip, while gently drawing the main stem towards the support.

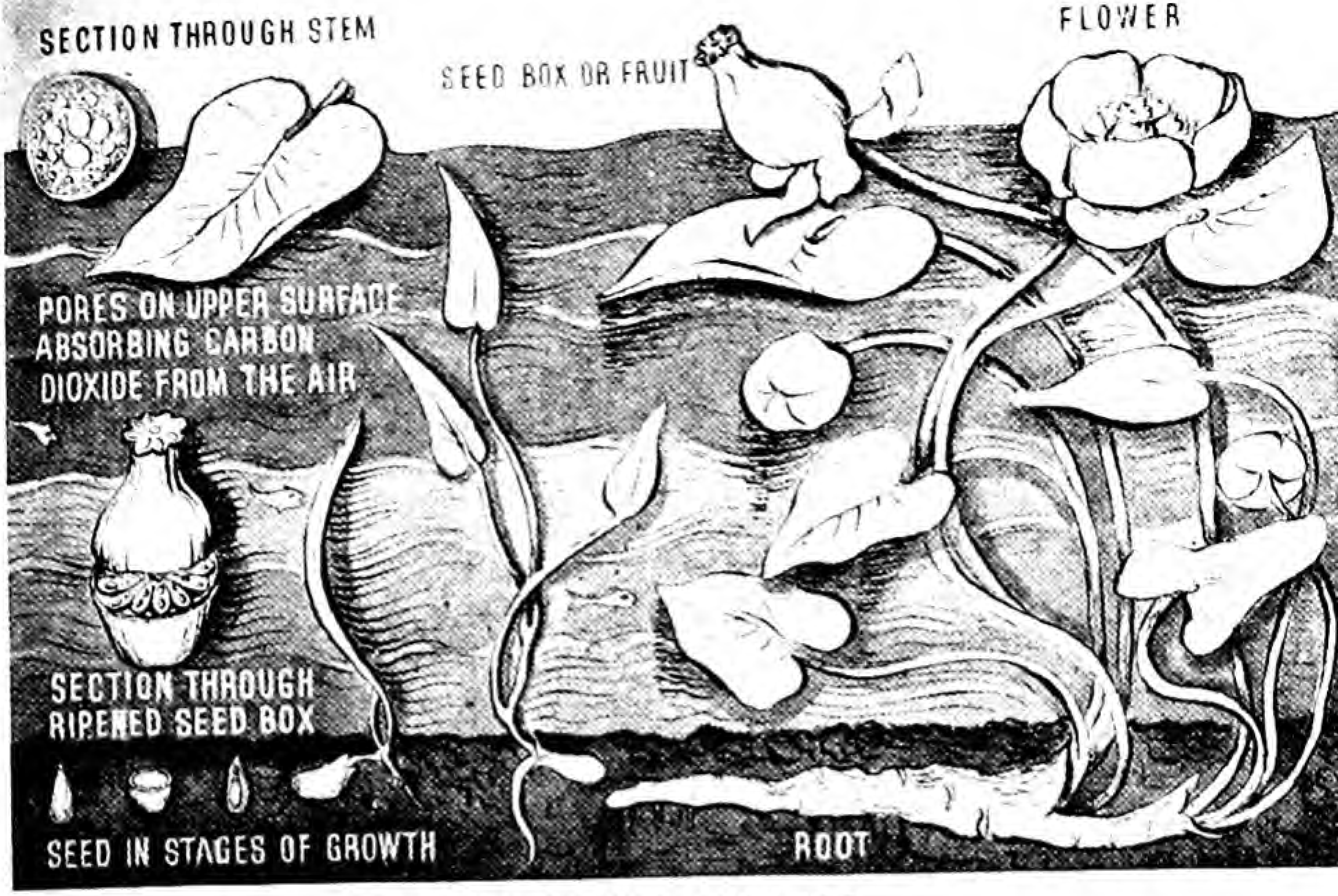
although their walls are thickened almost all over, there are a few narrow pits wherever the walls have been left thin. Unlike the vessels, however, these fibrous cells do not fuse with one another. Their chief function is to give additional rigidity to the stem.

In addition to the vessels and fibrous cells, the xylem also contains cells with squarish ends. They are not so long as the fibrous cells, however, and their fairly thick walls have small pits. They always contain protoplasm and a nucleus, and often, in addition, granules of starch. These cells are always found in contact with the vessels and form what is known as the woody or xylem parenchyma. Finally, in our survey of this part of the vascular bundle, it must be noted that the woody character of the cell-walls of the vessels is due to a substance called lignin, a chemical modification of cellulose which has the effect of rendering the walls much harder, and so prevents their collapse through pressure from the surrounding tissues.

Now let us have a look at the elements making up the bast or phloem of the vascular bundle. In our wallflower stem we shall find that the bast consists entirely of cells with soft walls of pure cellulose, and that the most important are of three kinds. First there are what are known as the bast vessels or sieve tubes. They are made up of long cells placed end to end and their distinctive feature is that their end walls are perforated by a number of fine holes, like a sieve; hence their name. They are called vessels because the cells of which they are composed are in open communication with one another by means of the perforations in their cross wall, or sieve plates. These bast vessels retain their

CREEPING AND CLIMBING PLANTS

Plants may climb in various ways, some by twining around any suitable support, some by clinging to it with tendrils or adventitious roots. Some, such as the hop, twine in a clockwise spiral, others, like the convolvulus, twine anti-clockwise, or against the sun,



HOW AN AQUATIC PLANT LIVES

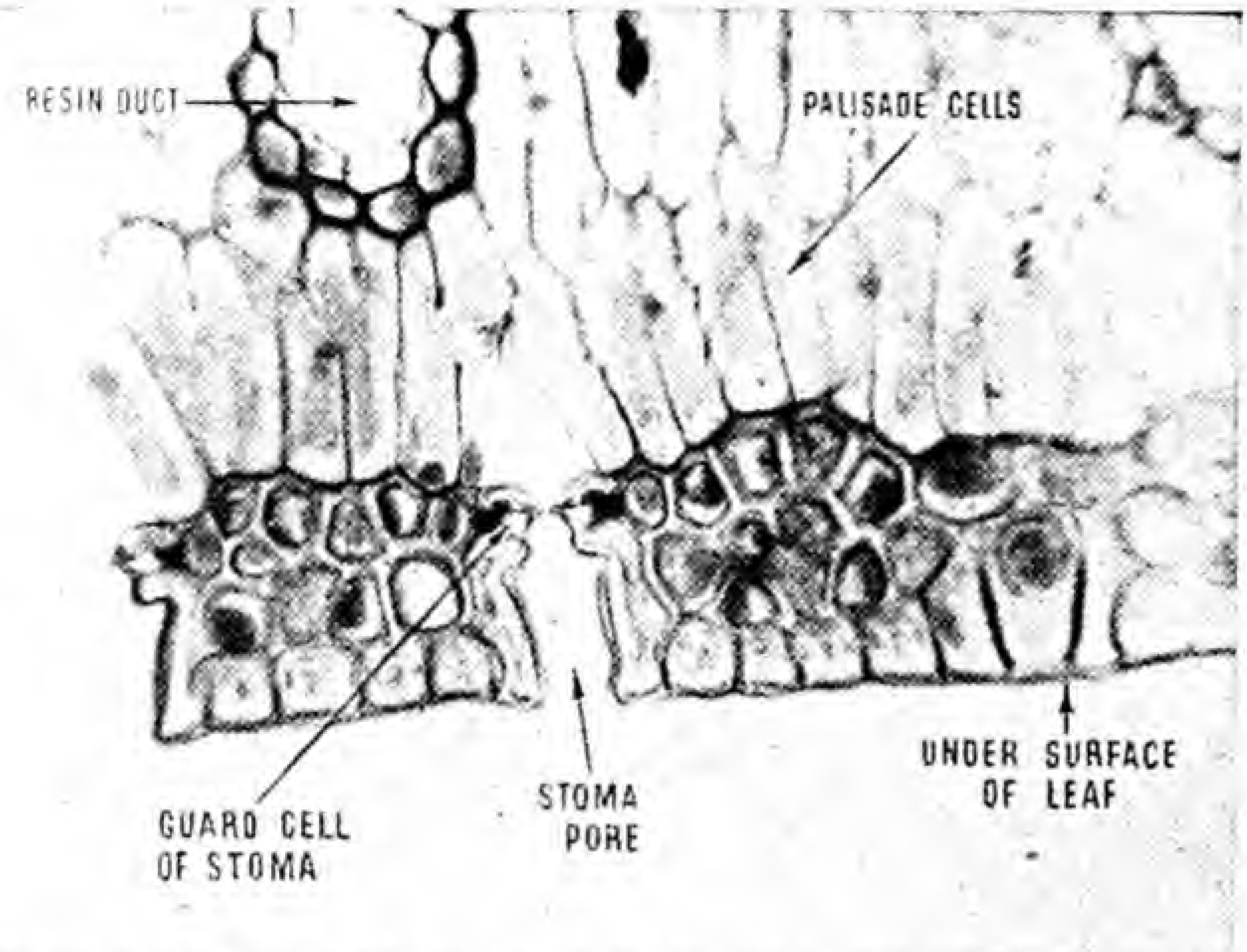
Plants which grow in water are called hydrophytes. Some are able to absorb gases in solution all over their surfaces but those whose leaves float on the water, like the water-lily, absorb and give off gases through the stomata on the upper surfaces of their leaves.

protoplasm, and also contain a slimy substance which is rich in nitrogenous compounds, and starch granules are also sometimes present. At first each of their constituent cells has a nucleus, but during the development of the sieve tube it breaks up into fragments and entirely disappears. Where sieve tubes are in contact with one another side by side, their lateral walls are perforated also in places so that through these and the perforations of the cross-wall sieve plates, the contents of the tubes are in continuous contact.

Intimately connected with the sieve tubes are narrow, longish cells, each densely filled with protoplasm and containing a large nucleus. These companion cells, as they are called, when seen in a cross-section of the stem, look as if they had been cut off from the corners of the sieve tubes, and as a matter of fact, that actually is how they originated, for both were formed by the division of the same mother-cell. The curious details of these sieve tubes and their companion cells are better seen in longitudinal sections of the stem of a cucumber or vegetable marrow, on account of their larger size in these plants, than in the small-stemmed wallflower. The rest of the bast portion of the bundle is composed of rather large, typical cells, each containing a layer of protoplasm lining the wall, and a single nucleus, and undergo no special modifications.

We now come to those layers of thin-walled cells called the cambium, which lie sandwiched in between the woody and bast tissues of the vascular bundle. On the inner side of the bundle these layers pass over gradually into the wood, and on the outer side into the bast. The cells in the middle of this tissue are in constant division, thus contributing new elements to both the wood and the bast tissues of the bundle.

What is known as the central cylinder of the plant stem consists of the vascular bundles arranged in a circle and of those parenchyma cells which, because they surround and unite the bundles together, form what is called the conjunctive tissue; those cells running up between the vascular bundles constituting the tissue forming the medullary rays. The cells belonging to this tissue bordering on the bundle are usually



UNDER SURFACE OF LEAF

Photomicrograph of vertical section of leaf of Scotch pine, showing stomata pore guard cells, resin duct and palisade cells. Each stoma opens into a large intercellular space in the spongy tissue called the air chamber. Guard cells regulate the opening and closing of the pores.

rich in grape sugar dissolved in their cell sap, and it is through these cells that the carbohydrates pass on their way from the leaves to other parts of the plant. The central part or pith of the stem is made up of large, rather elongated, squarish-ended cells which retain their protoplasm and usually contain starch granules.

Working outwards from the vascular bundles, we next notice a single layer of cells with slightly thickened walls, and with numerous starch granules included in their contents. This is known as the endodermis tissue and forms the inner limit of the cortex. The rest of the cortex consists of parenchymatous cells similar to those of the central pith, except that the outermost have slightly thickened walls and contain chlorophyll plastids, so that they can actually play a part in assimilation, though this function, as we shall see later on, chiefly belongs to the leaves. It is characteristic of all parenchyma cells, whether belonging to the central cylinder or to the cortex, that they do not fit closely together, but separate slightly at their corners so as to leave little spaces between them, and these intercellular spaces in the living plant are filled with air and with aqueous vapour, but no fluid.

Finally, we come to the rind or epidermis of the stem composed of cells which, for the most part, are elongated and have squarish, sometimes pointed ends which fit closely together. Each of these cells contains protoplasm and a nucleus, but no chlorophyll plastids. In the outermost layer of cells forming the skin or cuticle, the cell walls are not composed of pure cellulose, but of a substance called cutin, resembling cork, which is extremely impervious to water or watery vapour. Thus our survey of the structure of the plant stem, from the central pith to the outer skin, is complete.

Importance of the Leaf

We must now turn our attention to the structure of the leaf, the better to understand the very important part that it plays in the life and growth of the plant. The leaf is actually built up of the same kind of tissues as those that we have found in the stem, but with certain differences in arrangements and structure necessary for the special work they have to carry out. We have already learnt that the vascular bundles of the leaf are the direct continuation of those of the stem, and that they are the natural pipe-lines for the conveyance to and from the leaf of the cell sap which contains in solution those ingredients that nourish and help to promote the growth and life of the plant.

In fact, the general course of the veins is identical with that of the vascular bundles, each vein corresponding to a bundle now enclosed in a close-fitting sheath of parenchymatous cells, however, which differ from those of the rest of the leaf. It is to the

cells forming the tissues of the leaf itself, and particularly, the green chlorophyll-containing tissue, that we now turn our attention, for they are of prime importance in carrying on the functions of the leaf, in its relation to the plant as a whole.

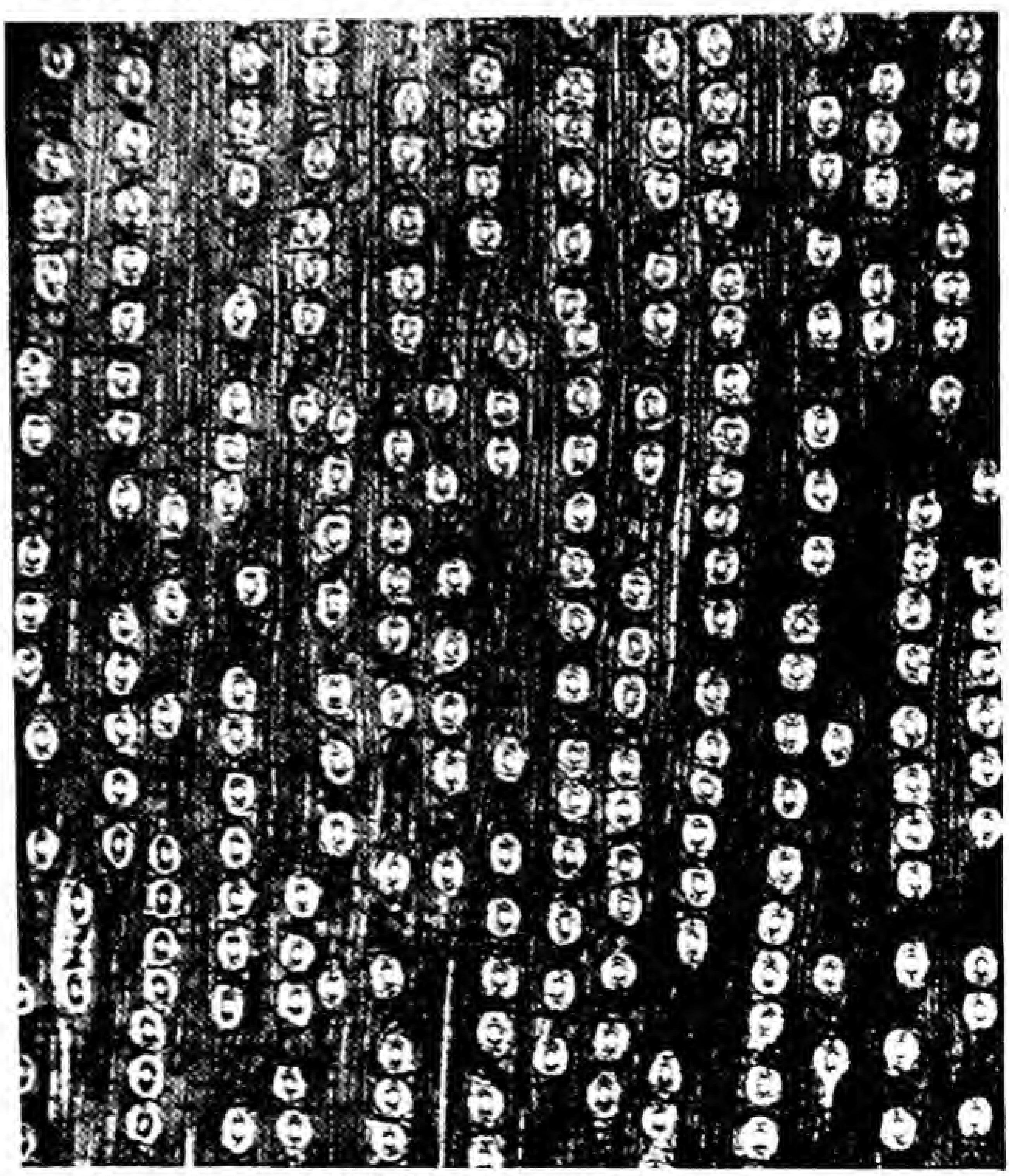
Looking at a thin transverse slice or section across the blade of the leaf, the first noticeable feature observed under the microscope is that the tissues of the upper present a totally different appearance to those of the lower part. We shall see that the skin, or epidermis, of the upper surface of the leaf consists entirely of a row of slightly oval-shaped, closely united cells whose outer walls are thicker than the others, and that they appear as if empty or only to contain water. Immediately below these epidermal cells the tissue is composed of several rows of elongated cells with squarish ends, closely packed together, and with their long axes at right angles to the surface of the leaf.

These cells contain an immense number of chlorophyll bodies or plastids, small green bodies, embedded in their protoplasm and chiefly ranged on the side-walls of the cells. This tissue on account of the upright and regular arrangement of its cells is called the palisade parenchyma, and is the characteristic tissue of the leaves of all the higher plants. Its cells are cylindrical in shape, and although very closely arranged, narrow intercellular spaces can be traced between them.

Immediately below, and joining the base of these palisade cells, are the very loosely arranged, irregularly shaped cells, with large intercellular spaces between them forming what is known as the spongy parenchyma. These cells also contain chlorophyll corpuscles, though in smaller numbers and uniformly distributed in the protoplasmic lining of the cell walls. It will be seen that the lower ends of the palisade cells never end blindly in an intercellular space, but always join on to the cells of this spongy tissue.

Lower Epidermis

Below the spongy parenchyma we come to the skin or epidermis of the lower surface of the leaf, on which there are numerous minute openings or pores, known as stomata, each opening into one of the large intercellular spaces of the spongy tissue. Numerous protective hairs also arise at intervals from the epidermis.



MAGNIFIED STOMATA

Under surface of a monkey-puzzle leaf. Through the stomata the plant interchanges gases with the air outside.

These small openings, or stomata, are very important organs and call for careful examination, for they display a beautiful example of perfect adaptation to a given function. Each stoma will be seen to open into a large intercellular space in the spongy tissue, called the air chamber. These chambers, again, are in direct communication with all the intercellular spaces of the leaf; and through them, with those of the whole plant. We see, therefore, that the stomata are the pores, by which the intercellular passages of the whole plant, containing as they do, air and water vapour, open into the external air.

In cross-section a stoma shows two guard-cells, as they are called, which differ in shape from the other cells of the epidermis. Their walls are very thick, especially at the corners facing towards the pore opening, so as to form what resemble lip-like, projecting ridges. Now, in the living leaf, the stomata have the power of opening and closing; as a rule, opening under the influence of light and warmth, and closing when it is dark or cold. The pore opens when the guard-cells become more curved, and closes when they straighten so that their sides are brought into contact. We shall learn more about the significance of this beautiful mechanism of the stomata later, when we come to consider the function of the leaf as a whole.

Tissues of the Root

To complete our survey of the structure of the living plant we must now note some of the differences to be found in the tissues of which the root is composed, paying more particular attention to those modifications associated with the extremely important function which the root has to carry out, for this part of the plant is far more than a mere means of anchoring it securely in the soil.

Unlike the stem, the root bears no leaves, its only appendages being the branching rootlets, and the very fine and delicate root hairs. These root hairs are most important organs, for they take up all the food that the plant obtains from the soil. It is the youngest growing portions of the root and root hairs which alone have the absorptive powers necessary to draw in from the surrounding soil the water and the various food-substances dissolved therein, required for the growth and nourishment of the plant.

In a relatively young root the middle is traversed by a strand of vascular tissue directly continuous with the vascular bundle system of the stem, but showing certain modifications. The wood or xylem forms a plate of tissue passing through the centre of the vascular system, with the bast or phloem grouped in two distinct bundles on either side. Owing to the diminishing diameter of the root, there is a greater concentration of the bundles, and a proportionate decrease in diameter of the central cylinder, which contains little connecting parenchyma tissue between the bundles, and usually has no pith. The outermost tissue, corresponding in position to the outer skin or epidermis of the stem,

HORSE CHESTNUT BUD

In early spring the outer winter protecting leaves wither and fall back. Halfway down the stem can be seen the scar left when a last year's leaf fell off in the autumn.

BEFORE THE FALL OF THE LEAF

Vertical section through leaf stalk on a stem in autumn, showing how Nature prepares like a skilful surgeon for the fall of the leaf. Note the dark ingrowing layer of corky tissue which will seal up the connecting cells when the leaf falls.

consists of thin-walled living cells. Many of these grow out into long slender hairs, each consisting of a single thin-walled cell with its protoplasm and nucleus.

These root hairs are much finer than the thinnest branchlets of the root, and therefore are able to push their way between the smallest particles of earth, to some of which they become quite firmly attached by the conversion of the outer layer of their cell wall into a sticky mucilage. That is one reason why you always find it impossible to pull a living plant out of the ground without bringing up a mass of fine earth, and why no amount of shaking will entirely dislodge the earth from the roots; some fine particles remaining firmly stuck to the delicate root hairs.

The growing point of the root has to push its way downwards through the soil and consequently is exposed to a good deal of friction. To guard against this it is provided with a special organ known as the root-cap, which consists of a sheath of tissue somewhat resembling in shape a thimble, and completely covering and protecting the delicate growing point of the root. As the root increases in length, this protective cap is pushed forward, receiving the brunt of the friction with the soil through which the root is forcing its way. Consequently, the outer layers of the root-cap gradually wear away, but are as regularly replaced from within by the active cells of the growing point of the root, which not only provide new tissue for the root-cap, but also for the lengthening body of the root. Just as the growing point of the root is protected by the thimble-like root-cap, so the growing point of the ascending stem is protected against varying climatic conditions by the leaves of the terminal bud which fold closely over it.

Having gained a general idea of the structure of a plant, of the tissues out of which its stem, root and leaves are built up, and some idea of their function, let us turn our attention to the all important questions of what food the plant requires to promote and maintain healthy growth;

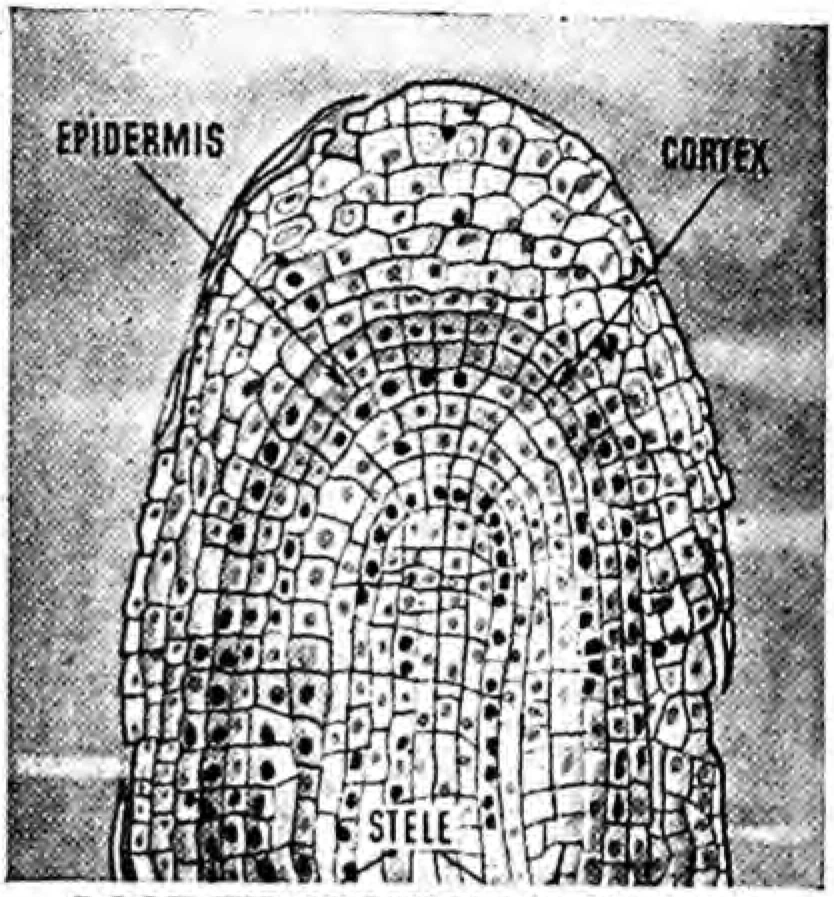
of how such materials are obtained and assimilated; and how plants respire. In fact, to learn something about those daily tasks which a plant has to perform as a successful living organism, quite as sensitive and responsive as any human being to good or bad conditions of environment.

Chemical Requirements

Many chemical elements have been found by the analytical chemist at one time or another in the tissues of plants, but it by no means follows that all were necessary or even entirely desirable for the health of the plant. On the contrary, they may in many instances simply have been absorbed into the tissues of the plant because, at the time, they happened to be in suitable solution in the adjacent soil. Many chemical substances, both organic and inorganic, are essential to the life and nutrition of the plant, the most important being carbon, hydrogen, oxygen, nitrogen, sulphur, phosphorus, potassium, calcium, magnesium and iron. Out of three of these elements, carbon, hydrogen and oxygen, both the cellulose of the plant cell and starch are constituted. The proteins which enter into the composition of the protoplasm contain, in addition, nitrogen and sulphur, while phosphorus is always a constituent of the nucleus, and unless a trace of iron be present in the cell content no chlorophyll can be formed. So far as the food obtained directly from the soil is concerned, the chemical elements composing it are always drawn up by the root tissues in very weak solutions.

Practical Experiments

From the following simple and easily performed experiments, we can gain a practical insight into the working of plant nutrition and the part which the roots play in drawing up those elements normally present in the soil necessary for the growth of the plant. Some seeds of barley or maize; a shallow box filled with damp sawdust; a few small jam or pickle jars fitted with corks; and a supply of nutritive or culture solutions which you can ask your local chemist to make up, or procure for you, are all the necessary impedimenta. Here is



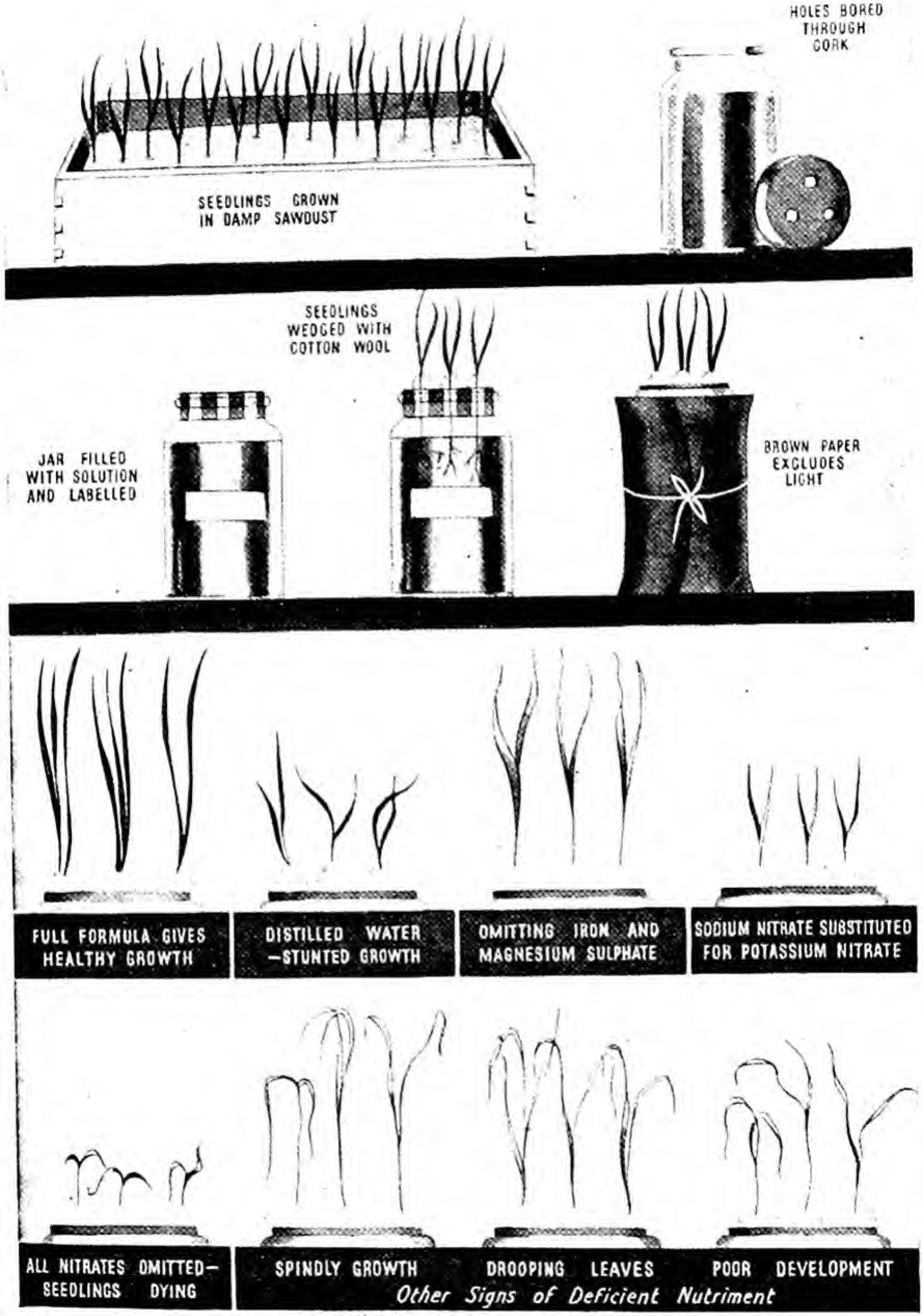
ROOT TIP HIGHLY MAGNIFIED
The central mass of tissue is called the stele. Surrounding it is the cortex.

a well-tried formula for the culture solution:—

Distilled water	..	100 ounces (5 pints).
Potassium nitrate	..	45 grains.
Calcium sulphate	..	25 ,,
Magnesium sulphate		25 ,,
Calcium phosphate	..	25 ,,
Sodium chloride	..	25 ,,
Sulphate of iron	..	Only a trace.

Ask your chemist to make up one bottle containing the complete formula; and other bottles each omitting one element, such as potassium, nitrogen (as nitrate), calcium, etc.

Three things should at once attract your notice in the above formula, namely, the large amount of water required for the proper dilution of the salts, so as to make them present in sufficiently weak solution to be easily absorbed and acceptable to the plant; that only a trace of sulphate of iron must be present; and lastly, the entire absence of carbon. The soil is never the source from which the plant obtains its supplies of carbon, that element in the case of land plants being obtained from the air by means of their green stems and leaves; while aquatic plants leading an entirely submerged existence obtain it from the air held in solution in the water. While a trace of iron is absolutely necessary, as already pointed out, for the formation of chlorophyll by the protoplasm within the plant



EXPERIMENT WITH CULTURE SOLUTION

Various elements in certain proportions are necessary to the health of a plant. This experiment will demonstrate the effects of the absence of any of these elements.

cell, it becomes harmful if present in the solution in excess. Two very necessary ingredients for the success of our experiments are care and patience.

Filling the Jars

Sow your seeds thinly in the box of damp sawdust, and allow them to germinate and grow until fully two inches in length. Drill one or two small holes in the corks, and fill each jar with one of the solutions, taking especial care to attach a label to each jar stating which particular solution it contains. Gently insert the root of one seedling only through each hole in the cork so that it dips down into the solution, and carefully wedge the little plant in position with the help of some cotton wool. Fasten thick brown paper round the glass sides of the jars so as to prevent light reaching the roots, and then place your jars in the window of a well-lighted room or greenhouse.

At the end of two or three weeks to a month, you will find that the plants are showing a marked difference in their behaviour. Only those planted in the jars filled with the solution containing all the salts in the formula will be healthy and show growth. The others will remain stunted having made little or no growth, and appear perhaps to be actually dying. Those in the solution from which all trace of sulphate of iron was omitted, will have grown for a time normally but it will be noted that any new leaves which may be developed are not green, but white; in fact, that they contain no chlorophyll. The reason why the first-formed leaves were green is that a sufficient supply of iron was already stored within the seed itself. We shall learn more about the formation of chlorophyll later on.

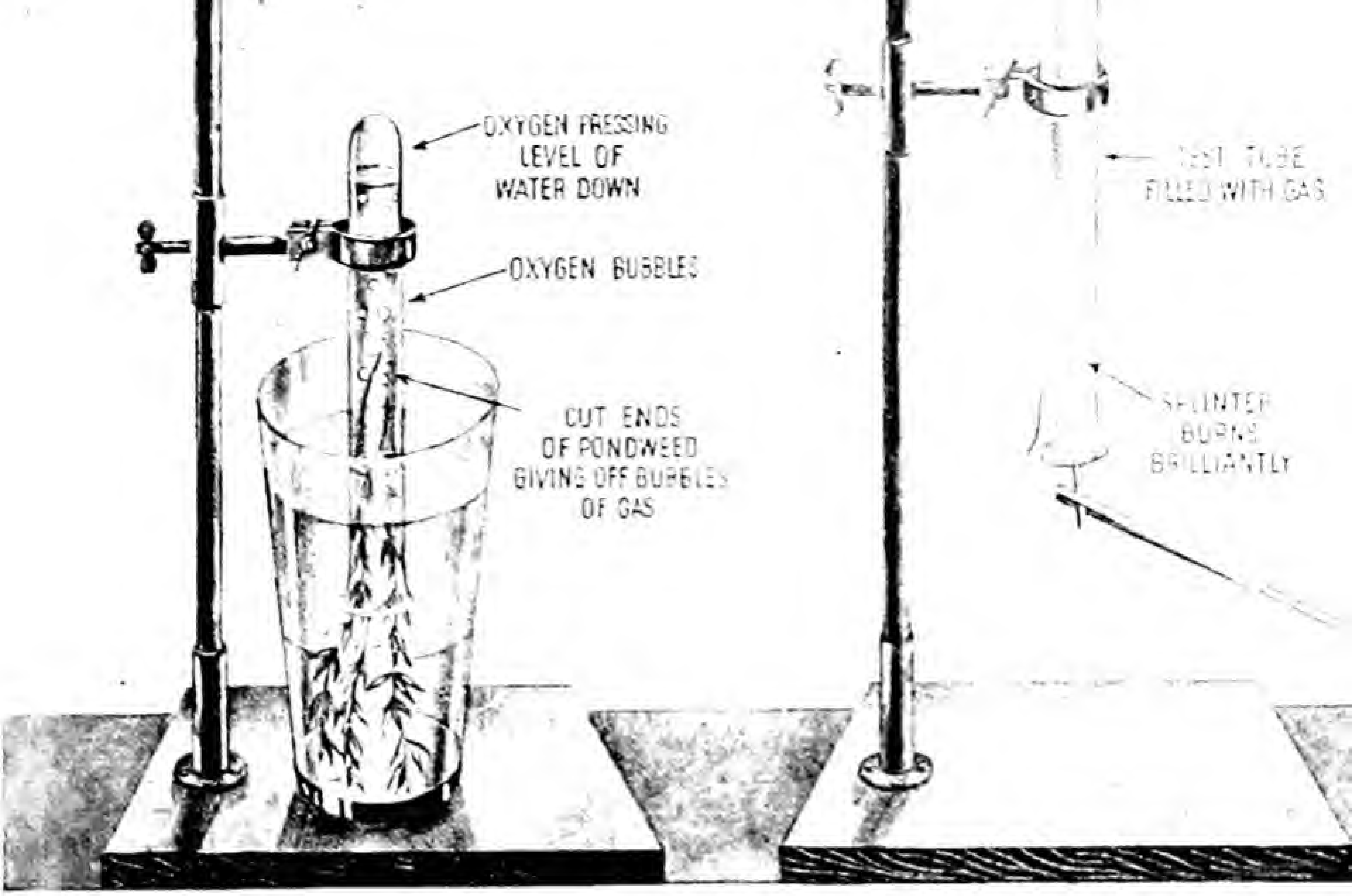
One other point in connexion with nutrition must be mentioned here. In most cases, plants cannot assimilate the free nitrogen present in the air—the seedlings grown in the solution lacking nitrogenous compounds will have starved, thereby demonstrating that they had been unable to obtain supplies from the air. There are, however, important exceptions to this rule, for plants belonging to the pea and bean tribe, the *Leguminosae*, are able under certain conditions to obtain their supply of nitrogen from the air by aid of a particular species of bacteria which swarm in small nodules growing on the sides of their roots.

These bacteria, known as *Bacillus radicicola*, live in the soil, from whence they penetrate, through the root hairs of the plant, into the cortex tissues of the roots, and by their presence there give rise to the nodules. These nodules are often noticeable on the roots of garden peas and scarlet-runner beans. The invasion, however, is not one of harmful disease germs, but really the friendly association of two entirely different organisms to their mutual benefit, such an alliance being known as symbiosis. The bacteria live on carbohydrates and at first also on albuminous substances supplied by the host plant, while the latter benefits by the power, possessed by the bacteria, of fixing free nitrogen and thus furnishing a steady supply of combined nitrogenous material. Thus the *Leguminosae*, to which order the peas, beans and lupins belong, would appear to differ from all other green plants in their mode of accumulating nitrogen.

Valuable Nodules

It has been proved conclusively that it is only when these bacteria are present in the soil that the nodules develop on the roots of the leguminous plant, and only when the nodules are formed that free nitrogen can be assimilated. Provided the nodules are present, the plant can thrive and assimilate great quantities of nitrogen in the absence of nitrogenous compounds in the soil. The discovery of this fact has proved of great value to agriculture, and today large crops of leguminous plants are often grown by the farmer for the sole purpose of ploughing them into the ground when mature and so to enrich the soil with nitrogen for other crops.

Our culture experiments having shown us how the roots absorb certain elements in solution that are normally present in the soil, we have now to consider how the plant obtains its supply of carbon, the most important of all nutrition elements, from



PHOTOSYNTHESIS IN WATER PLANTS

Light is essential for photosynthesis and this experiment should be carried out in daylight, preferably in strong sunlight. Small bubbles of gas are given off at intervals at the cut ends of the pondweed and collect at the top of the test tube. When sufficient has been collected the tumbler is removed and the gas tested with a glowing splinter. It lights up at once, showing the gas to be oxygen.

the only available natural source, namely the air.

The atmosphere contains carbon in the form of the gas known to the chemist as carbon dioxide. Now, the proportion of this gas present in the air is extremely small, amounting only to about .03 per cent; and yet it is from this small amount that the entire supply of carbon necessary for the majority of green plants is obtained. Carbon dioxide—often, though erroneously, spoken of as carbonic acid—is formed when carbon is completely oxidized. It contains the maximum amount of oxygen with which carbon can combine. In the presence of sunlight and with the help of chlorophyll plastids, the plant combines carbon dioxide with water to form simple carbohydrates such as glucose. Some oxygen is given back to the air.

That all green plants under the action of daylight give off oxygen, can easily be demonstrated. We have only to take one or two short stems cut from any green water-plant, such as the common Canadian pondweed (*Elodea canadensis*), to be found in most shallow streams and familiar to all who keep a few fresh-water fish in aquaria, and immerse them in a glass of fresh tap-water. If we place the glass with the water-weed stems in a sunny window and allow it to stand for a little time undisturbed, we shall soon see that bubbles are being given off from the cut end of the stems in a constant stream. It is possible to collect these bubbles as they rise, in an inverted test-tube filled with water, and to prove that they consist chiefly of oxygen by plunging a glowing splinter into the gas so obtained; the splinter will be rekindled.

If we keep the immersed stems in the dark, however, no carbon dioxide will be absorbed, and no bubbles of oxygen gas liberated. Assimilation depends upon light, air and temperature; for while all other conditions may be favourable, if the temperature is too low no assimilation will take place. It has been proved that the minimum temperature varies considerably for different plants, and that there exists for every plant a certain temperature below which the process of assimilation ceases. The energy that enables the green leaves of a

plant to do their work is derived from the sun, and unless there be light it is impossible for the plants to carry on the work of assimilation. Moreover, the green colouring matter cannot be formed by the protoplasmic chlorophyll corpuscles or plastids, without the help of light, in addition to the presence of the minute trace of iron in solution. Although these plastids are always present in the tissues of the leaves, they are unable to carry out that part of their work in the dark.

The two are most intimately associated, the chlorophyll being useless for the process of assimilation without the plastid, while the latter cannot function without the chlorophyll. Probably the duty of the chlorophyll is to catch or absorb certain rays from the sun, particularly those at the red end of the solar spectrum, and by the energy so obtained the plastid is enabled to carry out the process of combining carbon dioxide and water. In fact the green leaf of any plant may be likened to a highly skilled technician carrying out a series of delicate and intricate chemical reactions.

Most Vital Process

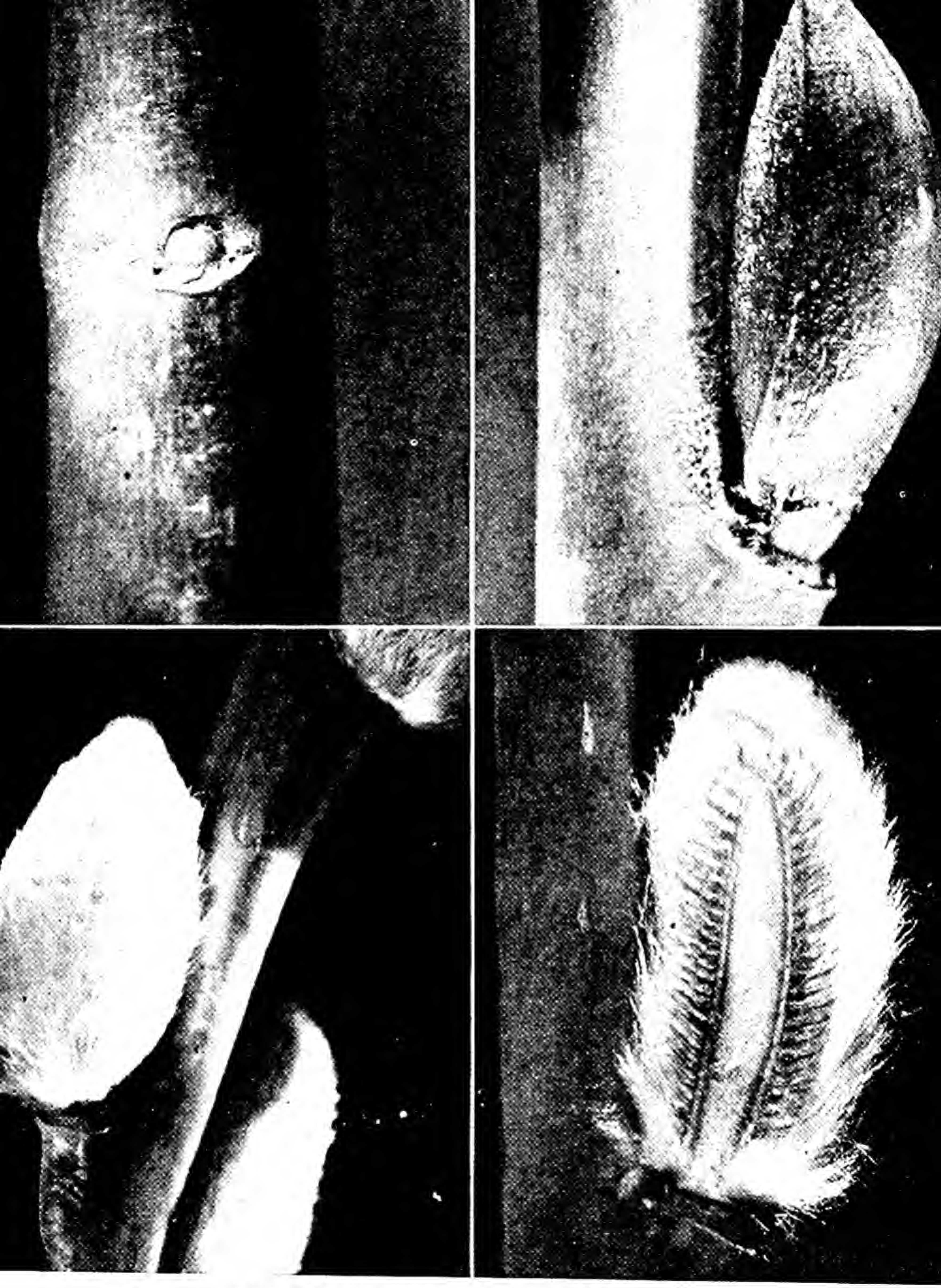
It is no exaggeration of actual truth to say that this process of assimilation of carbon from the carbon dioxide of the atmosphere is the most important physiological phenomenon known. Actually, upon its successful accomplishment depends the whole existence of both plant and animal life on earth. The herbivorous animals depend in the first instance entirely upon plants for their source of food, and they in turn are devoured by carnivorous animals and man.

After the carbon has been assimilated by the leaves of the plant, it is employed with other elements that have chiefly been derived from the soil through absorption by the roots, to build up the protoplasm, starch, cellulose and substances of which the tissues are composed. The first demonstrable product of assimilation is sugar, usually grape-sugar (glucose), or cane sugar, as the case may be. The glucose is formed from the inorganic compounds water and carbon dioxide. Then it is built up into more complex molecules of cane sugar. A certain portion of the sugar formed as an ultimate result of assimilation of carbon, is in most plants utilized by the protoplasm for the manufacture of starch, a form of carbohydrate convenient for storage because it is insoluble.

To render it easy for transportation it is reconverted into soluble sugar by means of a ferment known as diastase, derived from the protoplasm and found in the leaves of plants, and also in large quantities in germinating seeds, where great reserves of starch are usually stored to meet the future needs of the developing seedling. In the leaves, the diastase converts the starch which has been formed by the chlorophyll plastids, into soluble sugar, so that it can be carried away to other parts of the plant. The soluble carbohydrates are transported through the parenchyma tissue, particularly that part of it immediately in contact with the vascular bundles, either to the regions where rapid growth is taking place, such as the growing points of stem and branches and the cambium tissues, to be utilized in the formation of new cell walls; or they may be conveyed to those parts of the plant which form the natural store-rooms for food reserves. In these special regions of the plant the sugar may be stored up in soluble form, as in the root of the beet, or it may be reconverted into starch as in the potato tubers, the root of the turnip and in seeds.

Function of Stomata

The stomata, which are always present in the green parts of plants, are the organs by which the gaseous interchange between the leaves, the green stems and the atmosphere is constantly maintained. In the process of assimilation, the carbon dioxide passes through the stomata into the air-chamber and is thence absorbed by the surrounding cells whose thin cellulose walls do not hinder the passage of the gas. Thus absorbed, the carbon dioxide is at once dissolved in the cell sap, and is decomposed by the chlorophyll plastids. The mineral substances are absorbed in solution from the soil by the root hairs. This absorption is governed by the protoplasm of the root hairs. The weak soil solution is drawn



BIRTH AND DEVELOPMENT OF WILLOW CATKIN

Flowers of the willow are borne in catkins which on one tree may be male only and on another female. The flower is borne in the axil of a small scale or bract and has a very short stalk. The bud is enclosed in two sticky carpels which separate when ripe to liberate the seeds, each of which terminates in a tuft of silky hairs.

into the stronger cell sap through the membrane formed by the cell wall and the protoplasm. This is osmosis.

There are two distinct processes involved in the subsequent ascent of the sap, namely, root pressure and transpiration through the stomata. Thus root hair and stoma are linked together in regulating the passage of the sap. You have only to cut off the stem of one or two branches of a plant in the spring of the year, to realize that the water taken up by its root hairs is being steadily pumped upwards, for fluid will soon be seen oozing from the cut surfaces, flowing from the severed vascular bundles like blood from the severed veins of an animal. The cell walls of the root hairs are both elastic and easily permeable by water, and it is through the action of their protoplasmic lining that the entrance or exit of water is regulated. These cells, being already filled with sap, cannot indefinitely continue to take up more water.

As the pressure steadily increases, the cells become more distended until a point is reached when they can hold no more and a portion of the cell sap they already contain is forced into the wood or xylem system of the vascular bundle. As the process of absorption by the roots proceeds, the column of water in these tubular vessels rises, and thus eventually reaches the tissues of the leaves.

Excessive Water Loss

In the daytime, and under the influence of light and solar heat, the stomata of the leaves are active, and through them any excess of water is passed off into the air in the form of vapour. In many plants we shall find in addition to the stomata, the leaves have special water pores at their edges, provided to deal with excessive accumulations of water. The common nasturtium (*Tropaeolum majus*) of our garden is a good example, for on many a damp, humid summer night, large drops of water, often mistaken for dew, may be seen at regular intervals along the edges of the leaves. If these drops of moisture are gently wiped away, they will soon beseen tore-form, obviously showing that they have nothing to do with condensation from the atmosphere.

Transpiration and assimilation are carried out together through the agency of the stomata, for the ascending current of fluid also brings to the tissues of the leaves the sap containing in solution those substances without which assimilation could not take place. The general structure of the stomata has already been briefly described, but it is necessary here to examine their mechanism in rather more detail, the better to appreciate the function of the guard cells. Now we have seen that these guard cells of the stomata are the only cells belonging to the epidermis which contain chlorophyll plastids, and consequently are the only epidermal cells capable of carrying on assimilation. Thus, during the hours of daylight, they become active, forming new organic substances which pass into the cell sap.

Work of the Guard Cells

As the concentration of cell sap increases, water is absorbed by osmosis from the neighbouring cells, and thus the turgidity of the guard cells, necessary for their drawing apart to leave the pore of the stoma open, is accomplished. With the oncoming of night, the chlorophyll plastids cease to function, water is withdrawn, and the two guard cells as they become flaccid, tend to straighten out and so their edges, drawing toward each other, close the pore of the stoma which lies between them.

Plants and animals must breathe to live, and so long as they are in active life they are continually taking up oxygen from the air and giving off a corresponding amount of carbon dioxide. In green plants, the two processes of assimilation and respiration go on during the hours of daylight, but with an important difference of effect that at once distinguishes the one from the other. In the case of assimilation, the plant gains carbon at the expense of the carbon dioxide in the air, a constructive process by which more complex substances are built up out of simpler ones. In respiration, on the other hand, the plant loses carbon at the expense of its own protoplasm; it is a process involving combustion or oxidation, the product of oxidation, carbon dioxide, being given off again into the air. Respiration is not dependent upon daylight, but

SUNSHINE AND HEALTH

In the process of living all animals and plants give off energy which they derive ultimately from the sun. Both frog and honeysuckle flourish in it.

takes place continuously throughout the whole plant, carried on through the protoplasm, day and night, so long as the cells are active. It is only when the protoplasm is almost at rest, as in dry seeds or bulbs, that respiration becomes very slow indeed.

During daylight, the amount of carbon dioxide assimilated is greater than the amount given off by respiration; while in darkness assimilation ceases, and the carbon dioxide is returned to the air in the process of respiration. Broadly speaking, though with some exceptions, the volume of carbon dioxide given off by the plant in the course of respiration, is about equal to that of the volume of oxygen taken in.

Test Yourself

1. Of what, and how, are the tissues of a living plant built up?
2. What are vascular bundles? Briefly outline their shape, appearance and chief functions.
3. What is the chief work of the leaves, and how do the leaf-pores or stomata function?
4. What is the chief work of the root and the root-hairs?
5. Which of the inorganic salts in the soil are most necessary for the healthy growth of the plant?
6. How are the three vital life processes, transpiration, respiration and assimilation carried on, and by what particular parts of the plant?

Answers will be found at the end of the book.

FANG TEETH AT WORK

Lions prey on the larger herbivores, generally making their captures at night. They are tremendously strong and frequently break their victim's neck with a forepaw and then tear out the entrails with their claws. Another method is a bite with the powerful fangs in a vital spot. The flesh is torn up and devoured in large pieces.

CHAPTER V

HOW ANIMALS GET THEIR FOOD

As we saw in Chapter I, the kind of food which animals use distinguishes them from plants. Practically all animals must get food consisting of plant or animal material which already consists of complicated organic matter. Plants, for the most part, make use of simple materials like carbon dioxide from the air or salts from the ground, and build up their own complicated matter by utilizing the energy of the sunlight. This they can do because they possess the very remarkable substance called chlorophyll, which also gives them their green colour.

We have seen that because of this, while plants can remain fixed in one place and grow, using the gases and salts surrounding them, animals have to go and get their food in some way or other. In this chapter we are going to examine some of the most common ways and also look at some of the interesting exceptions, exceptions which led early naturalists to think they were dealing with plants and not animals at all.

Plants as Food

Perhaps the commonest general way of getting food, because it is the easiest, is to eat plants. Except in the deserts and at the poles, there are plants growing everywhere in the world. Even in the arctic *tundra* of Lapland or Siberia, there are mosses and lichens available all the year round on which the reindeer feed. For this reason, land animals show a tendency to feed on grass, leaves or grain of one sort or another. They may not have to travel far to get it and as it is growing it replaces itself as an apparently inexhaustible supply.

You have only to think of the common birds to see how true this is; the sparrow, chaffinch and pigeon are seed and vegetable eaters and are only too common. Among mammals, we find all the rodents—mice, voles, rabbits, hares, squirrels, guinea pigs, beavers—feeding on roots, growing shoots, grass, bark, pine cones, and vegetable matter generally. The great herds of bison, deer, antelopes, etc., are all grass feeders and there are probably no other groups of animals to which our minds more naturally turn when we think of large numbers of animals as these.

Among the invertebrates, look at the insects. All the caterpillars live on plants; beetle grubs bore into wood and many, like wasps, rely on fruits for a good part of their short lives. Some groups tend to specialize in decayed vegetable matter. Among fish, the carp are a good example and, of course, earthworms extract their food from the decaying matter and bacteria etc. in the soil; wherever you have humus in the soil, there you find earthworms.

The only limit imposed on these common feeders is the amount of food available to them. Towards the edge of the grass plains, where the desert is not far away, the plant life is very sparse. It is then a race to see if grazing animals, like sheep, can cover enough ground in a day, to meet enough blades of grass or small herbs, to satisfy their hunger and make the extra energy expended in covering so much ground worth while. Watch sheep or cattle grazing on our lush grasslands; there is no hurry, food is plentiful.

In the semi-desert lands, the sheep feed almost on the run, snatching at tiny plants as they hurry past. Oddly enough, the limit may be reached in most luxuriant conditions, if the animals are rather lazy in habit. In the thick forest, elephants can stand and tear down as much as they want almost without moving. But, since they live in a herd, they soon clear the immediate surroundings, which are left stripped and bare. They then have to move on to another patch. The vegetation is unable to recuperate on these spots fast enough to

keep a continuous supply available for a herd to live in the one place.

The next most common method of getting nourishment is to eat animal food of some kind. Animals which do this are called carnivores [vegetable (or plant) feeders are called herbivores], while those who eat principally small insects, snails and worms are called insectivores, although they still fall into the same category from our point of view. To catch their food, carnivores have to be much more active than herbivores; *their* food can run away.

Sometimes, the hunter runs its prey down, like the wolves and cheetahs; others rely upon stalking until within range of a sudden leap, like the cats or the fox. Great numbers of fish feed on other kinds of animals, often themselves smaller fish. The great shoals of mackerel which are caught close to the shore, have been pursuing the small fry known as brit, usually composed of the young of several species of fish.

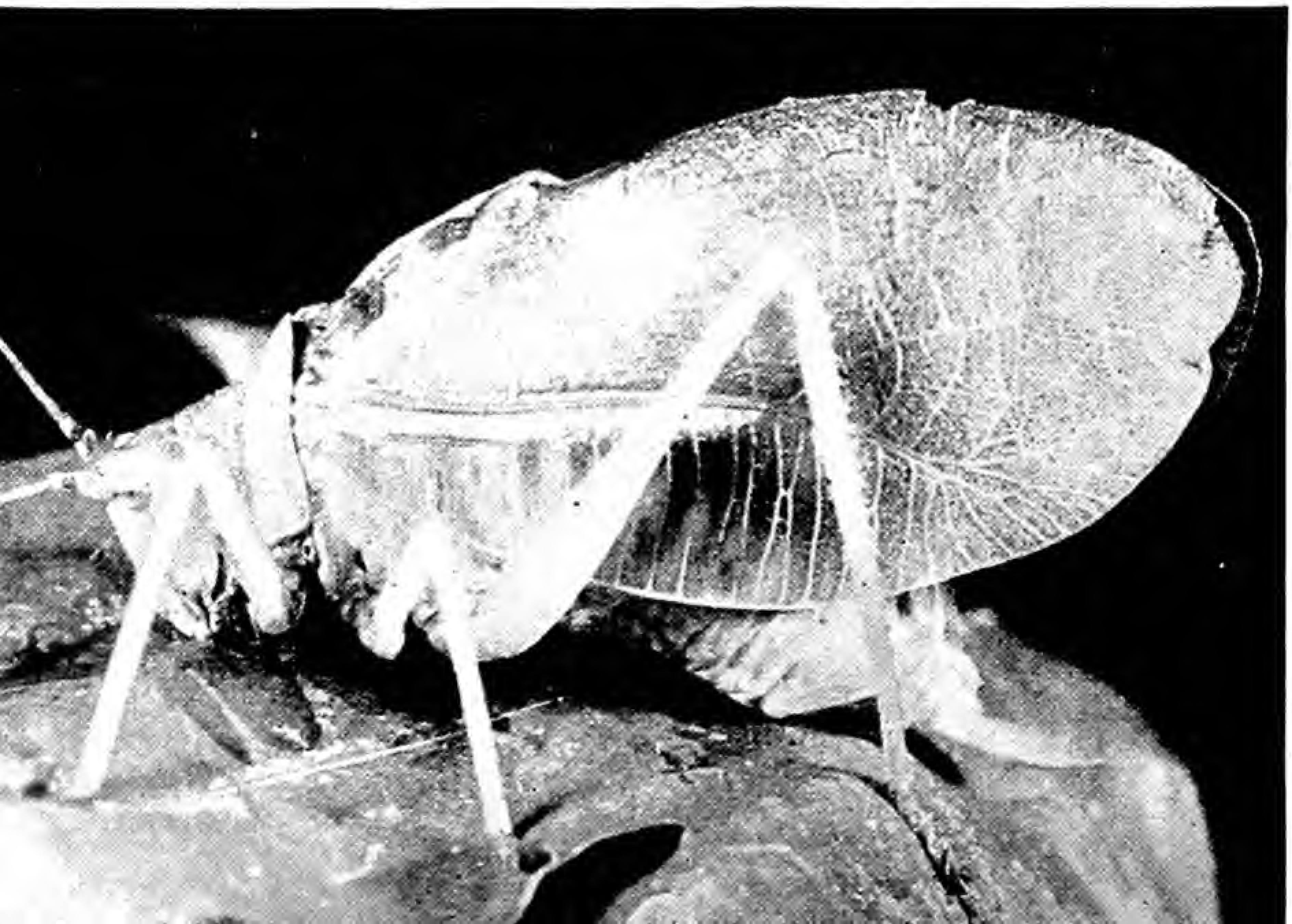
Instead of the stalking of the land animal, we find that many fish catch their prey by remaining immobile until the victim comes within easy reach of the huge, extendible jaws. Pike do this in fresh-water streams, while the John Dory, which feeds on prawn-like creatures, may even indulge in slight and stealthy movement before making the final gulp which draws the prey within its grasp.

Carnivorous animals display all sorts of devices for holding on to their prey. Fish feeders have to grasp and hold slippery prey, and we find that seals and sea-lions have modified teeth with many fine points instead of the blunt or rounded teeth of other mammals. Alligators and crocodiles feeding in water, and many fish, have fine needle-like teeth in profusion for much the same purpose.

Claws in mammals and talons in birds are also adaptations for holding the struggling prey of carnivores. Everyone knows the sharpness of a cat's claws, although dogs and wolves, which do not leap on their prey, but run it down in packs, rely on the teeth of the whole pack

GREEDY FEEDER

American grasshopper (the katydid) is seen eating an oak leaf. Its mouth parts are of the biting type. These insects are voracious herbivores and are very destructive.



EATING ON THE MARCH

Elephants, largest of the herbivores, use their trunks to make food more accessible. The herd moves on when one patch of the jungle has been stripped of vegetation.

to hold their victim and drag it to the ground.

It is interesting to note that the eagles and falcons which catch their prey by striking with their feet have strong, powerful talons. Watch a kestrel drop out of the sky onto a vole; the legs are stretched down and the talons close on the victim. The beak is brought into use only when the bird begins to eat. A peregrine falcon may strike a rabbit, which is large and heavy, and, for some time, until it is dead, the struggles of the rabbit will drag the falcon along the ground. Unlike these birds, the owls have weak feet and talons; they capture their prey with their strong, extremely hooked beaks, which, although short, are broad in proportion and give a firm hold.

Killing by Squeezing

One of the most extraordinary methods is used by the big constrictor snakes, whether boas or pythons. That these snakes kill their food by squeezing the prey to death, at the same time reducing its thickness to manageable size, is well known. It is not often realized, however, that these snakes throw their coils almost instantaneously round their prey and hold it in three, four or more coils so that escape is impossible.

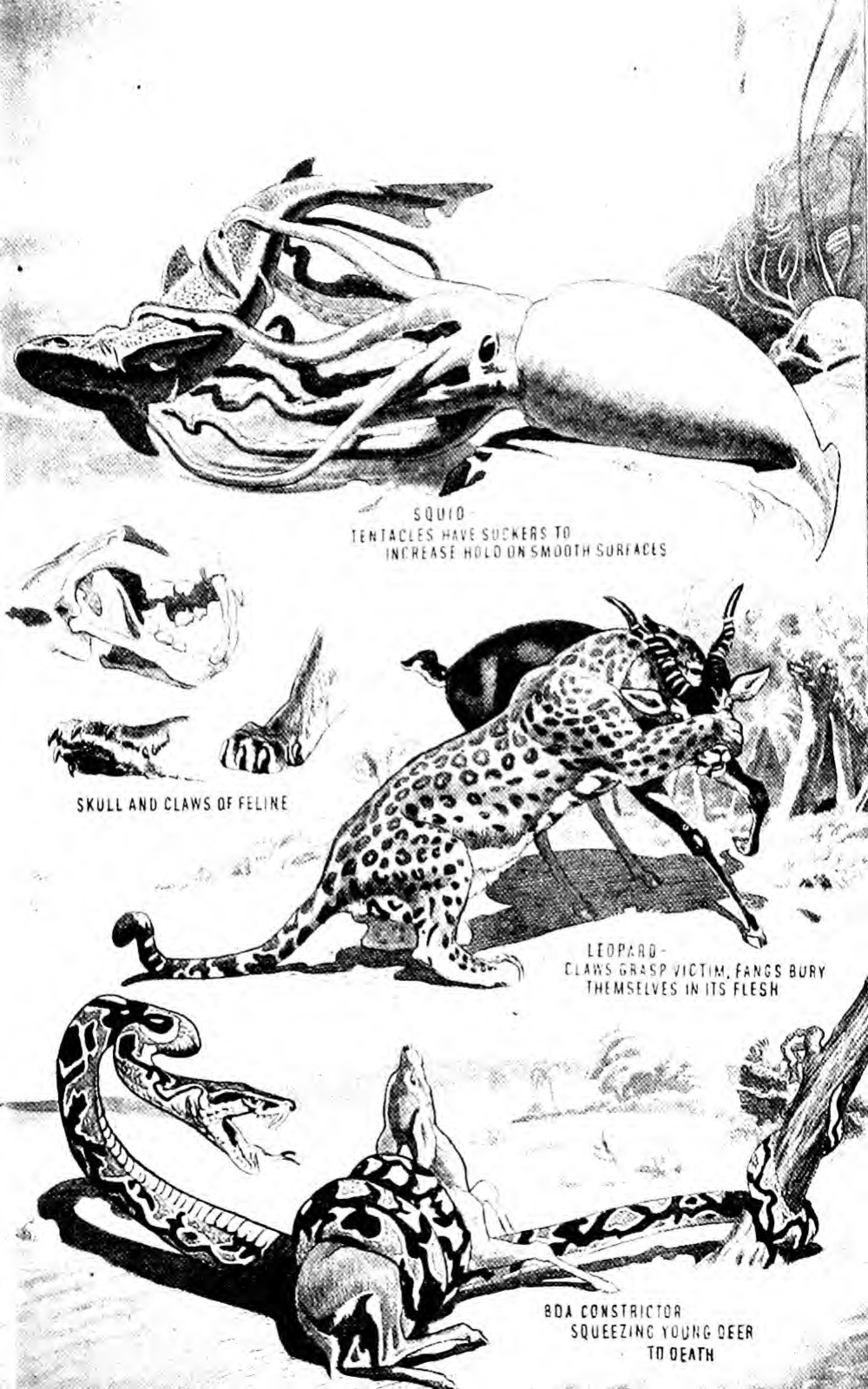
One of the disadvantages of the carnivores, besides that of having to catch the victim, is that they have to find their prey first. Plant life, we have seen, is to be found almost everywhere, but animal prey is scattered about and constantly on the move. A carnivore must search an area to come on its prey and this area may be quite a wide one. The larger the carnivore, the larger the territory it roams and tends to treat as its own hunting ground. If you live in the country you soon become accustomed to seeing a particular kestrel hawking a series of fields or a hillside.

A stoat or weasel takes up residence in a small district and can usually be met with, within its hunting area. Only when prey becomes so scarce as to make hunting unprofitable does it move on to "pastures new." Some carnivores have shortened the odds by combining together. It is now well known that young lions tend to hunt in packs, some moving up wind and round in a circle so that game is driven down-wind to their waiting companions whom they join later at the feast.

Many carnivorous animals, because of

CARNIVOROUS ANIMALS

How they grasp and hold their prey


SQUID -
TENTACLES HAVE SUCKERS TO
INCREASE HOLD ON SMOOTH SURFACES
SKULL AND CLAWS OF FELINE
LEOPARD -
CLAWS GRASP VICTIM, FANGS BURY
THEMSELVES IN ITS FLESH
BOA CONSTRICTOR
SQUEEZING YOUNG DEER
TO DEATH

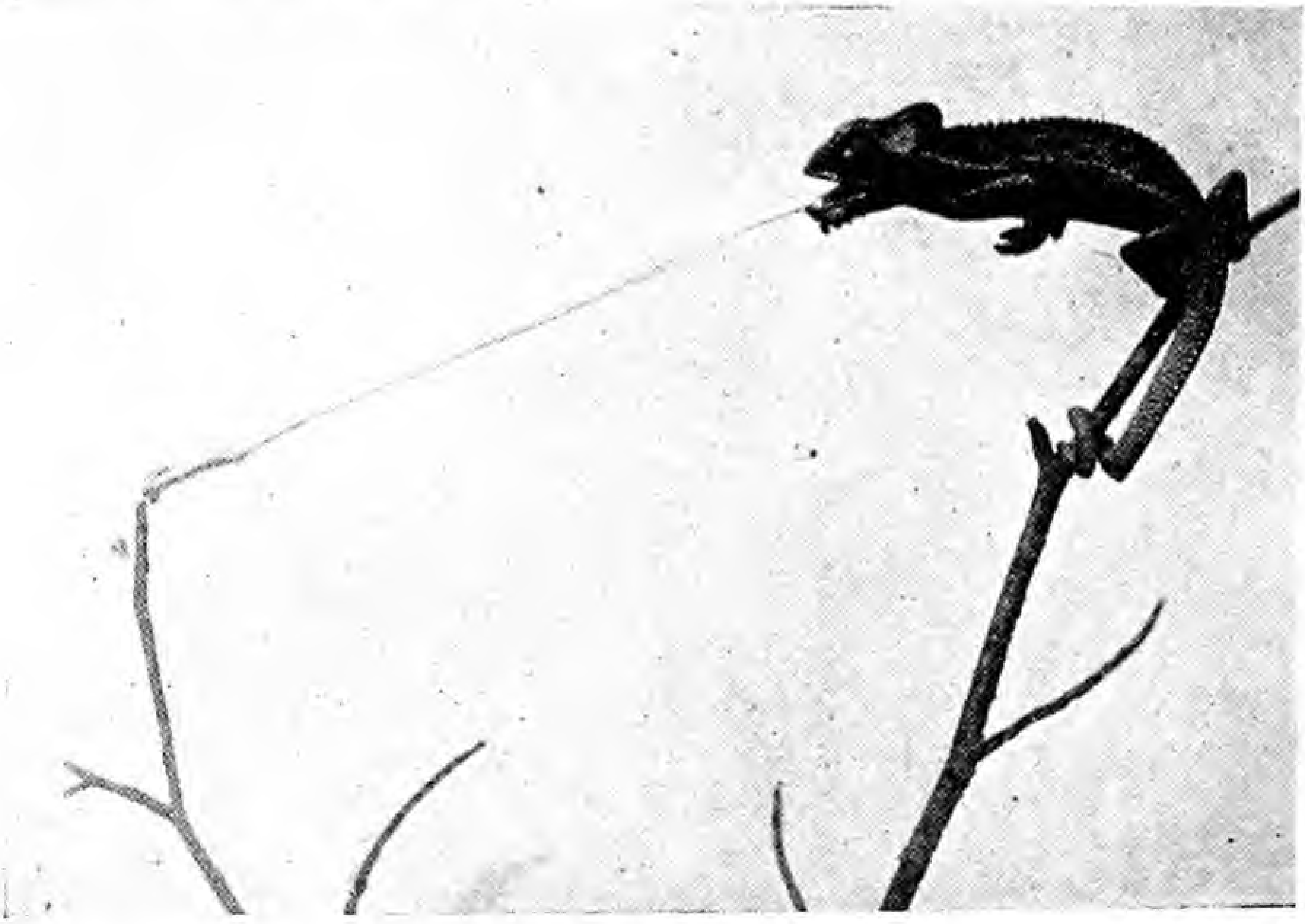
the difficulties involved in catching their prey, feed only at infrequent intervals. When they do kill, however, they gorge themselves to repletion. The difference between this type of feeding and that of the grazing grass feeder who keeps going steadily most of the time, is very marked and is connected with very considerable differences in digestion and in the make-up of the stomach and intestines.

How the Lower Animals Feed

By drawing examples from well-known large mammals and birds we tend to forget the lower animals, but here, also, we can find examples of both these principal ways of getting food. In the *Mollusca* we find that, generally speaking, the Gasteropods (snails and slugs) are herbivorous. We all know the damage slugs do to our gardens, and an even closer parallel to grazing is found in pond snails and limpets and winkles which crawl over the surface of stones and rocks and scrape off the vegetable growth of algae which can always be found as a film there, just as grass and herbs cover the ground.

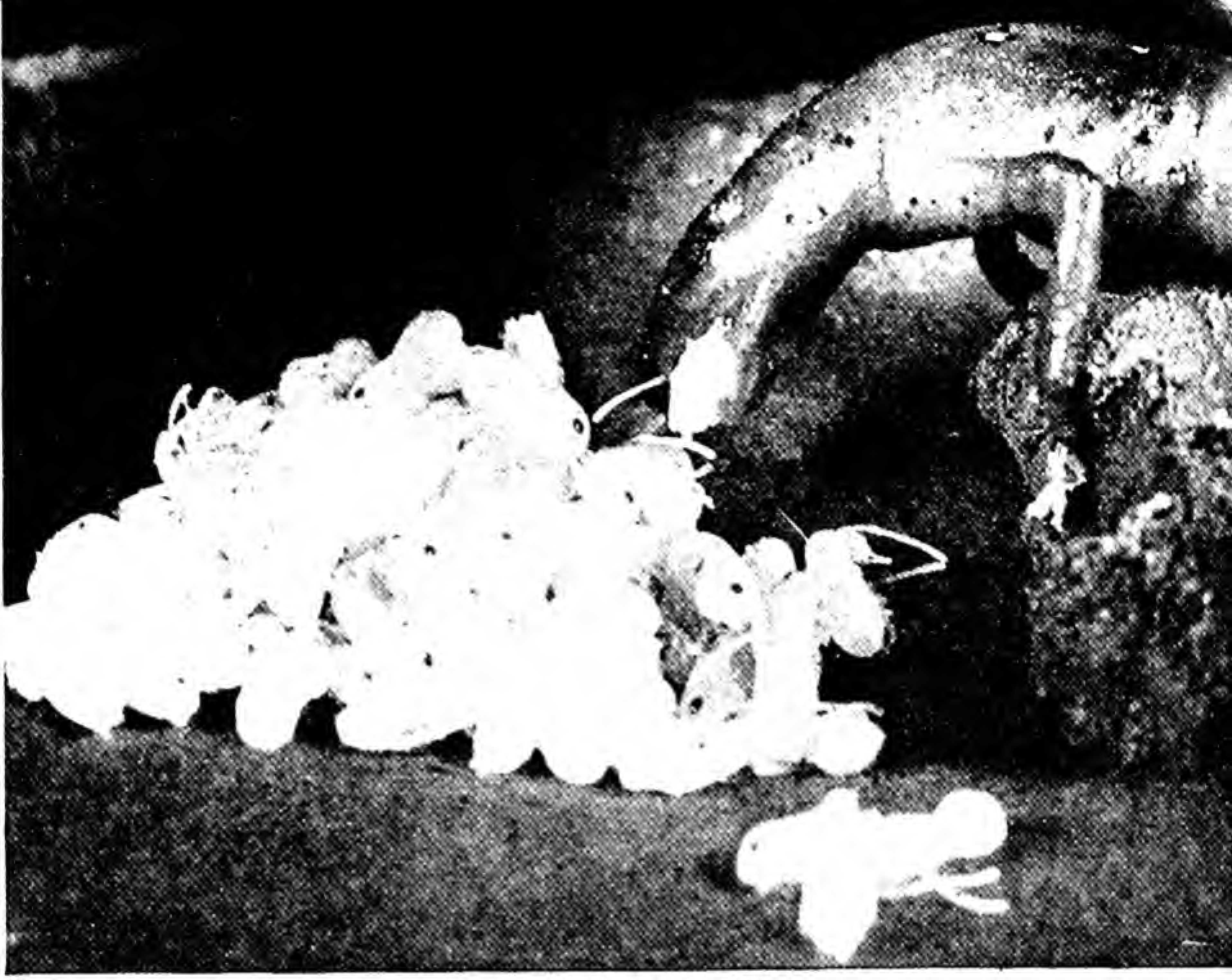
However the Cephalopods (squids and octopuses) are carnivorous, seizing their prey with their long tentacles or arms covered in suckers (instead of claws) with which to cling to their food, tearing it apart with the powerful jaws which are two long horny projections shaped like a parrot's beak.

If we examine the third class of molluscs, the *Pelecypoda*, or bivalves, we find an entirely new kind of feeding mechanism which is the third chief type found among animals: this is known as filter-feeding. The principle involved is that the food is very much smaller than the animal feeding on it and is collected by being filtered out of the surrounding water irrespective of whether it is animal or vegetable, or, for that matter, indigestible mineral material. The only thing that counts is size; small enough to pass into the entrance and



SHOOTING TONGUE

Remarkable tongue of the chameleon is seen here, making its deadly aim at a fly or other insect. It has a sticky secretion at the tip which makes escape for the victim impossible. It is withdrawn into a long sac in the floor of the mouth by muscles.



NEWT DEVOURS INSECT GRUBS

Newts, like frogs and toads, to which they are closely related, are carnivorous. They feed on insects and small worms both on land and when they enter the water to breed.

large enough to be held back by the filter.

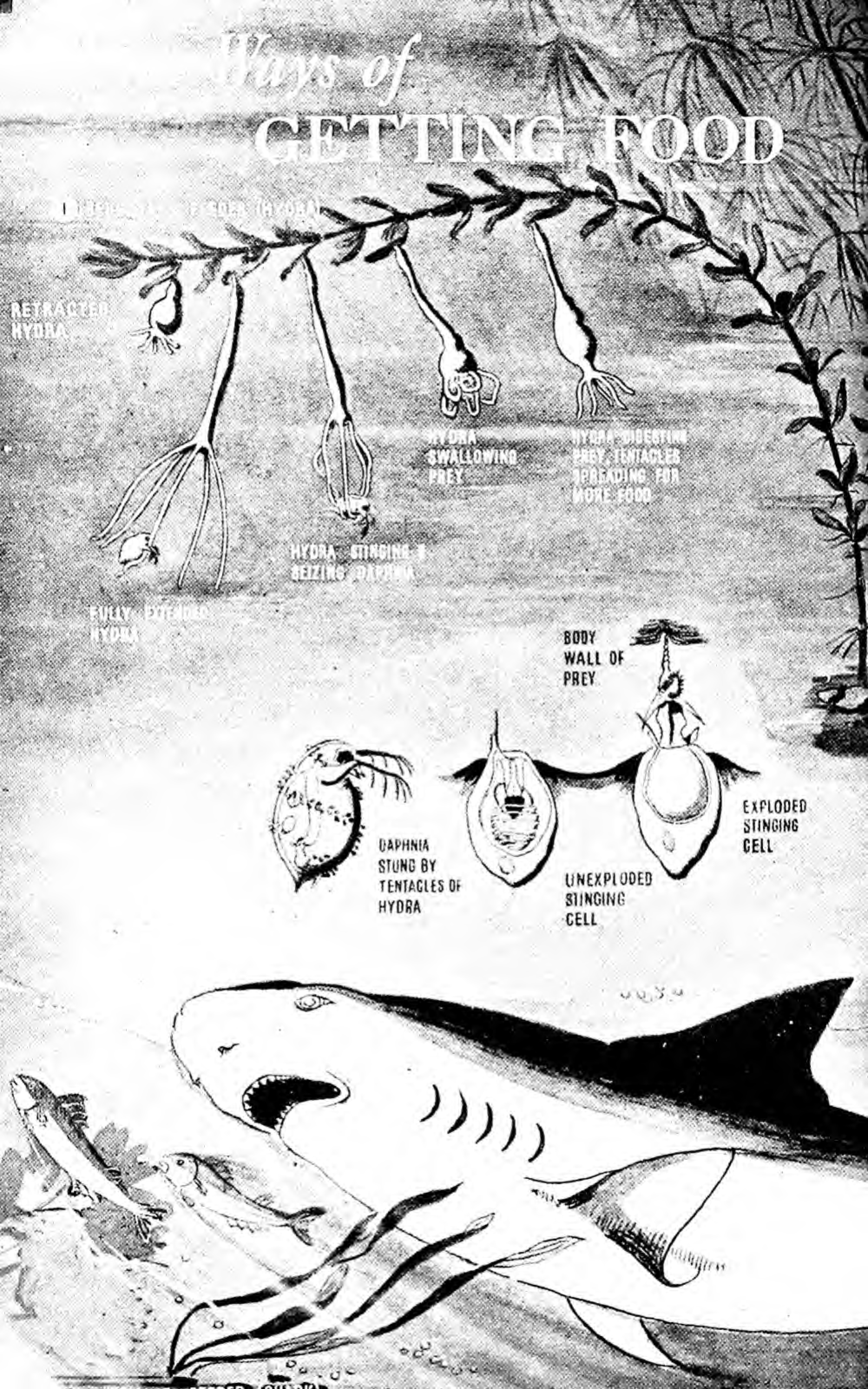
The organ which the animal has developed for this is, of course, the filter. It may be comprised of all sorts of materials. In bivalve molluscs it consists of hundreds of thin fleshy threads, joined at intervals for strength, between which the water current must pass. In *Crustacea* like the fairy and brine shrimps, it is made up of the fine, horny (chitinous) hairs which are found on the edges of the limbs and which sweep the current of water along as well as collect the food particles. In many fish there are projections and filaments, supported by stiff cartilage, on the gill arches; they can be easily seen in the throat of the cod. Whales filter the krill with the whalebone which is made of large modified hairs on the lips, in fact, a moustache.

Necessity for Water Current

One thing is common to all filter feeders, besides the presence of a filter. There must be a current of water passed onto the filter and through it. If the animal is very active, the current is made by the animal's passage through the water. If the animal is stationary, the current is made by the water passing through the animal. Whales, fish and *Crustacea* go into the first category; bivalves, sea-squirts and sponges into the second. Those which pass a current of water through themselves all use a similar device—cilia. Cilia are fine, protoplasmic filaments or hairs, arranged in serried rows, which beat rhythmically in one direction.

To see a wave-beat sweep across a field of cilia is rather like seeing a gust of wind cross a field of corn, except that the movement of the corn stalks is made by a current of wind whereas a current of water is made by the beating of the cilia. Cilia work best as current producers when they are operating in a space not much more than two or three times their length across. Then all the water in the space or tube can be strongly influenced by the ciliary beat. On the filter of the bivalves, the cilia can beat down between the gill filaments and

Ways of GETTING FOOD




CUTTING
JAWS OF
SHARK

create a strong and rapid current of water through the slits.

Only in sponges do we find something a little different. Here, there are many isolated filaments or whips, called flagella, which do not work in the co-ordinated way cilia do, but are longer and if sufficiently numerous, as they are in sponges, can produce just as large a current.

We have now dealt with animals which either go out in search of their food, be it vegetable or animal, or filter it from the water they cause to pass through their filtering apparatus. In all cases they are to some extent active in getting hold of food.

Passive Feeders

These methods cover the vast majority of animals but there is yet another method, that of simply remaining passive and taking whatever comes along, which at first sight looks as if it would be so inefficient for an animal that any that adopted it would soon become extinct. There are, however, some groups which have proved very successful feeding this way. The sea-anemones and corals, for instance, remain fixed and catch whatever happens to come within reach of their tentacles. It is the development of these tentacles which has shortened the odds against catching their prey. Look at a hydra waiting for prey. The tentacles are many times the length of the body and can intercept prey over a wide area.

Stinging Cells

Another device has also been evolved by these animals, this time to ensure that most of the prey intercepted do not get away. This device is the stinging cell, which shoots off as soon as anything brushes against it, pierces it with the barbed thread and so holds it. Hundreds and thousands of these stinging cells may fire off at a single water flea which blunders against a hydra.

It must be remembered that in the tidal area, the water is moved about by wave action and so these stationary animals are able to encounter quite a lot of water. This is another compensation and it is worth noting that most (certainly all the most successful and abundant forms) are littoral, that is, are found on and near the shore. Hydra, however, lives in fresh water.

There remains one group of animals of a very different kind; the internal parasites. So long as they remain in their host they do not carry out feeding movements in the ordinary sense. They are surrounded by nutritive material, whether in the intestines, in the blood or elsewhere. Many of them do not even have a mouth or gut of their own but absorb nourishment through their skins, like tape worms. Of course, they have their difficulties but once they have got their "host" everything is easy. We find that the adaptations are not directed so much towards feeding methods as towards ways of finding their host and remaining attached. This is as important from the aspect of maintaining the species in existence by breeding, as from the point of view of feeding.

Relative Size of Food

Something should now be said about the size of food relative to the animal feeding. Broadly speaking, the food may be larger than the animal or it may be smaller. This applies equally whether the food is plant or animal or dead matter. It is obvious that if the food is very much larger than the animal there must be some preliminary way of tearing pieces off. Dozens of examples come to mind ; caterpillars eating plant leaves, cats and dogs tearing off pieces of meat and so on.

To take the opposite extreme, we have the filter-feeding animals referred to above, and seed-eating birds. In between, we have a great variety of devices for reducing the food to proportions suitable for further treatment. These are usually referred to under the general term of mastication but may comprise ordinary chewing as we know it by the molar teeth of a mammal, crushing of food between tongue-like pads and teeth as in some fish, rasping food into small particles with the radula of snails, cutting food into smaller pieces with the mandibles or gnathobases of insects, *Crustacea* or Arachnids, and tearing small pieces off with the five teeth of sea urchins. Such mechanisms are external to the

LIFE CYCLE OF A LIVER FLUKE

Parasite which attacks the livers of sheep. The pond snail is the intermediate host between the excrement (in which the eggs are found) and swallowing by the sheep. If the eggs fall into the water, or waterlogged ground, they hatch into larvae which swim about until they find a pond snail to bore into. Otherwise, they cannot survive.

animal for the most part, but some indulge in internal mastication.

We find the gastric mill of crabs and lobsters most efficient in pounding the small fragments torn off and cut up by the mandibles and other mouth parts into minute particles which can enter the excessively fine tubes of the so-called liver for digestion. Birds have no teeth and either bolt their food whole or swallow pieces torn off by their beaks. In their gizzards they grind these to pulp between hard, horny plates operated by powerful muscles.

Although all birds living at the present time have no teeth, but use the gizzard mechanism, it must not be concluded that each major group of animals is so uniform. A consideration of the mammals alone would soon show the error of such a conclusion. Mammals have a definite specialization of teeth into incisors, canines, premolars and molars. The incisors are adapted for seizing and cutting their food: nearly all grass-eating mammals tear the grass off with their incisors. The canines are long spike-like teeth for holding on to prey and are best developed in the carnivorous forms. The pre-molars and molars

are for smashing and grinding up the food, real mastication; the former only are found in the first, or milk, dentition but are supplemented by the additional molars.

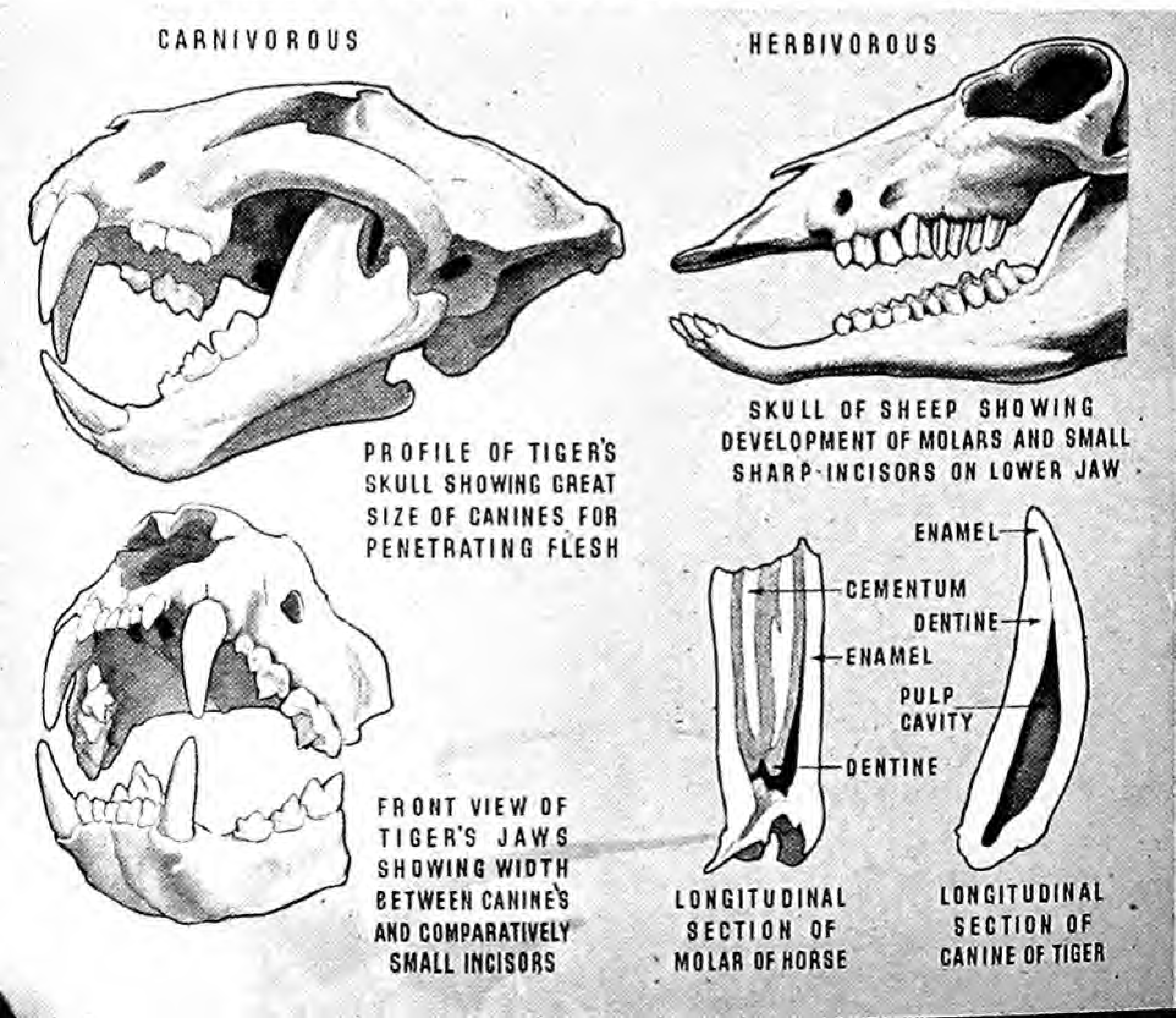
Within the class of mammals we find all kinds of variations of this basic arrangement. First, the molars, vegetarian, carnivorous and omnivorous feeders, show considerable differences. Vegetarian animals have molars with elongate ridges either across the teeth (elephants and rodents), or lengthwise (cattle and horses). Carnivores require strong, broad teeth for pulping the soft, stringy meat and for crushing bones; their teeth have sharp but powerful points set on a broad base. Omnivorous forms have a more generalized tooth, half way between the two, such as we find in pigs, bears and man.

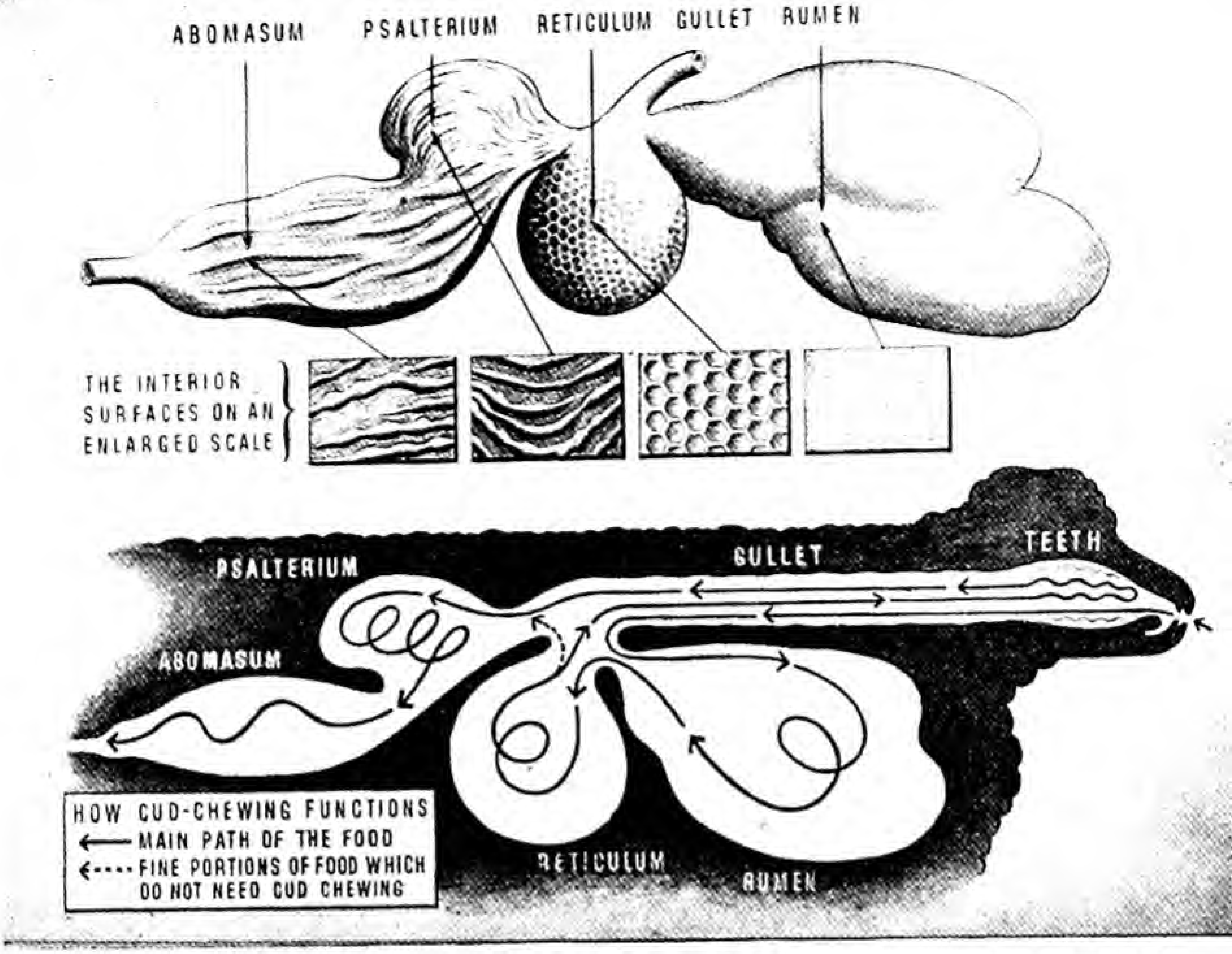
Fish eaters do not require this sort of specialization; they must hold onto their slippery prey, and a number of small points are developed on each tooth in the seals while the toothed whales and porpoises have a great number of small teeth each with a single point. Rodents have specialized their whole dentition. The incisors are reduced to a single effective pair which grow throughout life and are chisel-edged, the canines are missing altogether and the molars are purely for grinding.

It is among the insects that we find the clearest cases of the adaptation of a standard mechanism to numerous methods of feeding. What is regarded as the primitive condition of insect mouth parts is found in the cockroaches and grasshoppers. It consists of tiny appendages designed to handle and masticate small and fairly soft material, such as grass and other fine

DIFFERENT TYPES OF TEETH

Animals' teeth are adapted in different ways to cope with the varying types of food which they eat. Carnivores have strong canines for penetrating flesh. Herbivores have sharp incisors for tearing grass. The arrangement in the jaw varies greatly.





DIGESTIVE SYSTEM OF A SHEEP

Digestive organs of a ruminant or cud-chewing animal. The food passes first into the rumen and thence into the reticulum, where it is partially softened. Then it is returned to the mouth to be re-chewed. Digestion is completed in the abomasum.

leaves, root tips and so on. One development of these appendages is quite straightforward in the boring insects whose mandibles are so strong that they can gnaw into hard grains (weevils) or into seasoned oak (death-watch beetle) or even into lead by accident! Such a modification is not remarkable, but the production of an apparatus for sucking up fluids is quite another matter, yet it has been evolved at least five times among the insects:

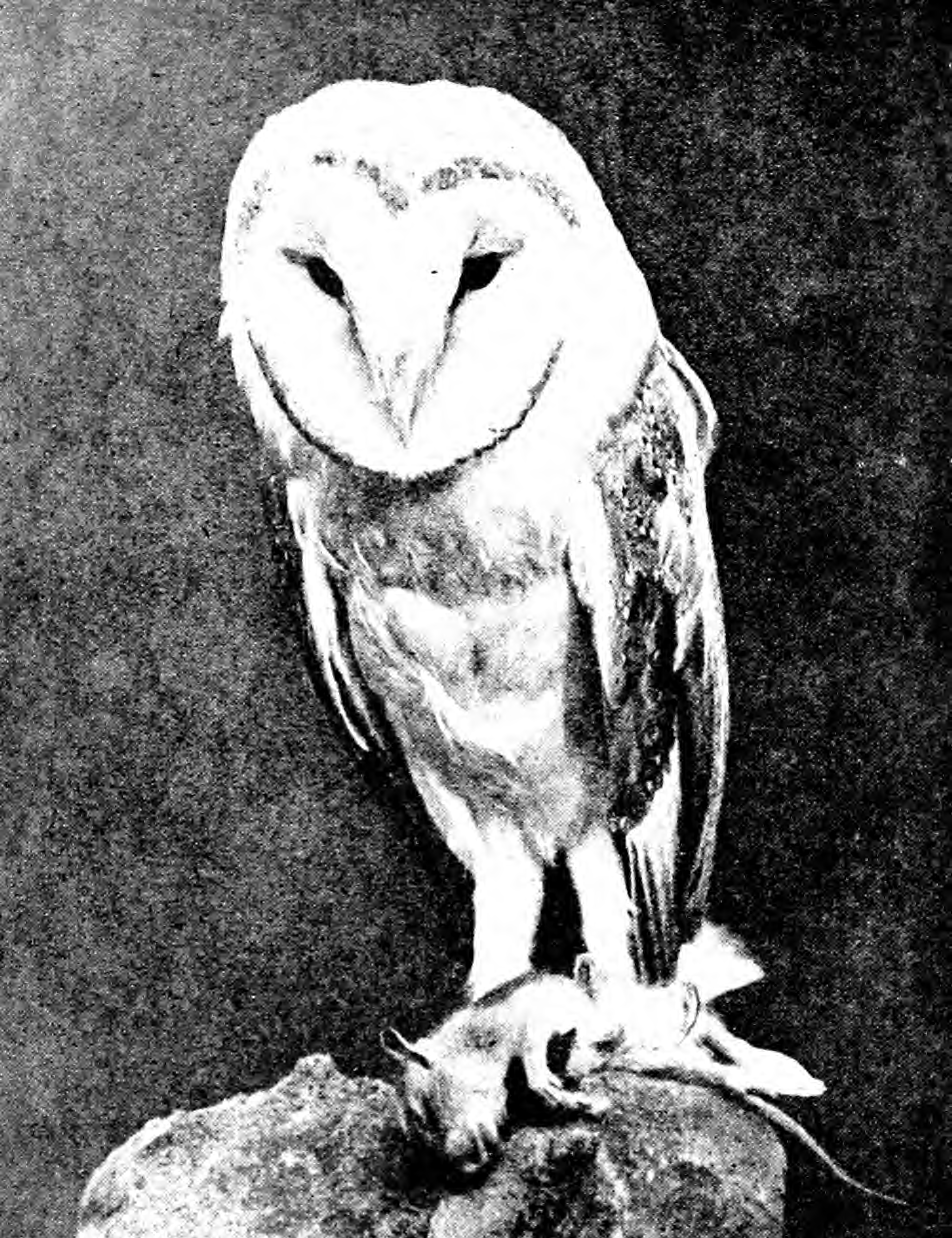
(1) the plant and blood-sucking bugs (aphids and bed-bugs),
(2) blood-sucking flies (gnats and mosquitoes),
(3) butterflies and moths,
(4) lice, and
(5) fleas.

In each of these, the same basic parts are made use of but by adaptations have come to be used in quite different ways.

The mouth parts of bees and wasps are again adaptations, this time to a combination of licking and biting. The nectar, or honey, is licked up by one part of the apparatus, the rest being used in the moulding of wax (bees), chewing of wood into pulp for nest-building (wasps) and general manipulation of food-stuffs in the many activities of the community.

We must now come full circle in this matter of food supply and consider again, from a different angle, the relations between an animal and its food. We have seen that all sorts of devices and mechanisms in the structure of animals enable them to feed in most of the conceivable ways. What we must do now is to find out what could happen if an animal became too efficient at gaining its food. Put simply like that, the answer is plain, the food supply would become exhausted and the animal would starve and probably die. In real life, however, it is not so simple or plain, and we come across some of the most complex relations known between living organisms.

In the first place, very few animals are quite so conservative as to confine them-

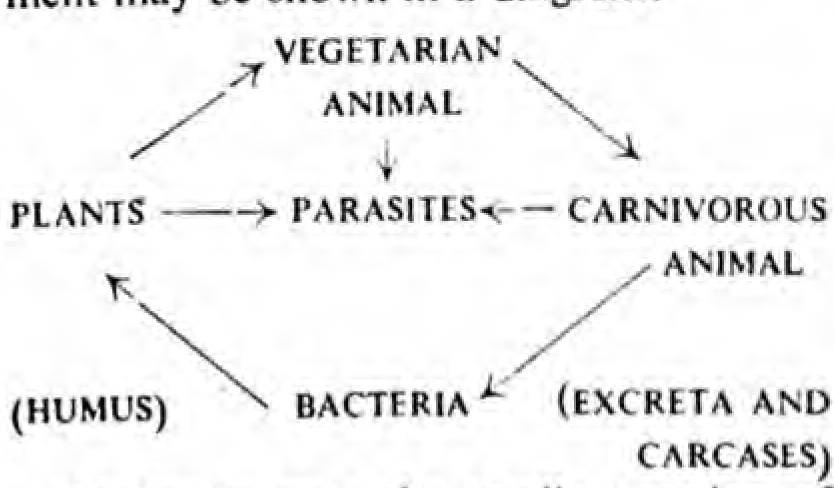


BARN OWL WITH ITS PREY

All birds of prey have a highly developed power of vision, which enables them to sight their prey from far off or, as in the case of the barn owl (seen above with a young rat), in the hours of darkness when it hunts. Owls have comparatively weak feet and talons: the capture and kill are made with the powerful hooked beak.

selves to one sort of food. Most eat a wide range but have preferences within that range. Even then, the preferences are relative, so that a very common source of food, although it is not a first preference, will be eaten more frequently than a rarer foodstuff even though the latter is highly prized. Seen in this light, the problem becomes more complex but instead of a fatal ending we can see that a balance between the availability of a food and the demand made upon it becomes established.

The next point to consider is that we have seen there are both herbivores and carnivores, and that a sort of chain of food sources is established by these relationships. Thus grass and other herbaceous plants are eaten by sheep (selectively, by the way, as experiments on grazing show) and that among the food-stuffs of man are skeep. Man, in turn, is preyed upon by parasites, while the excreta are broken down by bacteria and provide food material for vegetation. The general statement may be shown in a diagram:



Obviously, even the smallest section of such a cycle, treated in detail, is very complex. To continue the previous example, sheep are not the only animals feeding on grasses, man eats many other animals (and many plants besides), while dozens of land animals contribute excreta and carcases for treatment by bacterial decay, and there are other organisms, such as dung beetles, which utilize excreta in their life history.

Sections of such food relationships are known as food-chains and it is one of the aspects of an animal-plant community which has to be studied to obtain a proper idea as to how the community lives.

Besides noticing the tendency to proceed from plants, through vegetarian animals to carnivores, we must see two other phenomena which appear alongside. The first is a decreasing numerical order, thus a large number of plants is wanted to feed comparatively few herbivores while the carnivores are much fewer still. The last part of this chain is very clear in any small area of countryside where the number of hawks, owls, foxes, weasels and badgers is probably small (two or three wild farm cats would be a large addition) but the number of rabbits, mice, voles and small birds is obviously very much greater.

The second is an increase in size particularly in the animal chain. Thus carnivores are generally larger than their prey (foxes than rabbits, cats than mice, and so on) although there are exceptions to this as to every other generalization.

Test Yourself

1. Why is the commonest way of getting food to eat plants?
2. Why are carnivorous animals generally more active than herbivorous animals?
3. Describe some of the devices by which carnivorous animals secure and hold their prey.
4. How are some of the simpler animals equipped to secure food?
5. Explain some of the devices for reducing food to proportions suitable for eating.
6. Why does the arrangement of teeth in mammals vary?
7. How are the mouth parts of insects adapted to the food they eat? Name a few special adaptations.
8. What is a food chain? Can you make one up, with specific examples?

Answers will be found at the end of the book.

ANIMAL LIFE IN A HEDGE

Any of these animals may be seen in the hedgerow of a country lane, for here they can find the type of food and shelter which suits them best. Birds find seeds and insects to eat and shrubs in which to nest. The rabbit eats green leaves and burrows in the grassy bank. The weasel loves mice and shares the hedgehog's taste for birds and eggs.

CHAPTER VI

THE RESPONSE OF LIVING THINGS TO ENVIRONMENT

The story of any means of human transport is full of romance and adventure. The history of the aeroplane, for example, never fails to excite the imagination, and there is no less adventure, and considerable humour, in the evolution of the motor-car, the steam-engine and even the ordinary bicycle.

But we take our legs for granted, as we do those of familiar animals. It seems natural for the horse to trot on all fours, the monkey to climb, bats and birds to fly. But was it always so? Did walking, or flying, just happen? The story of evolution shows the propulsion of any living body under its own power to have been a long and tedious process of development, with many failures by the way and some most spectacular triumphs.

Amoeba—which the reader will already have met in these pages—represents animal life at its lowest. It has nothing which by the widest stretch of imagination could be called a brain or a heart, no skeleton, no true muscles, but it is an animal in that it depends for existence upon organic matter, and it moves: moves with a freedom immeasurably beyond that of any plant.

By thrusting out portions of its minute, gelatinous body, amoeba can advance, side-step or reverse, to an unlimited extent, though always at a tardy pace, in water or in soil. It thrusts backwards, and so forces itself forward to another point in space.

First Animals With Shells

At some remote period in the world's history, long before the first recorded fossils of some five hundred million years ago, creatures akin to amoeba were able to collect minerals from the surrounding water and make shells for themselves to live in. These were often exquisitely fashioned and of infinite variety. Such creatures are the foraminifera whose empty, discarded homes largely compose the South and North Downs, the cliffs of Dover, and other well-known chalk deposits. Millions of miles of the ocean floor are covered with a fine, heaving, treacherous ooze, a semi-fluid mud—the shells of countless billions of foraminifera and allied creatures.

In the fullness of time, much of it will be compressed into chalk rock, and some submarine eruption of perhaps two million years hence upheave it to form chalk cliffs or downs as yet unnamed. The animals which live in these tiny shells thrust out from minute holes arms of living jelly substances—protoplasm—and so somehow contrive to move themselves from one spot to another in the eternal quest for another meal. Of the remains of such moving homes are built not only the chalk hills of Britain, but the hard limestone used to fashion the pyramids of Egypt.

Somewhat higher in the scale of life is the sea-anemone. This creature, so static to the casual observer, can slowly glide along on its base and thrust out tentacles like the multi-coloured petals of some wonderful flower unfolding. The sea-urchin—a mere globular box of shell to the eye—can walk up a pane of glass, and the starfish can not only do the same but turn itself right side up, if laid on its back, in a few minutes. Like the urchin, it does this by means of what look like little glass rods, each with a round sucking disc at its end. But like the sea-anemone's tentacles, they are really hollow tubes of thin but very strong skin, filled with water.

The anemone's tentacles, like the bulk of its body, and also the tube feet of the starfish and the sea-urchin, are very similar to the fingers of a glove. They are pulled in, from the top downwards, when not in use. When wanted, the glove finger can be pushed out, inflated by water, the result

of a complex mechanism which we shall not attempt to describe here. Every part of an animal, or plant, is in constant movement by just the same forces as move its outward shape. We are here concerned chiefly with the exterior.

There may seem little analogy between the garden worm shoving the soil behind it, as each of its hundreds of rings pushes against the soil, and, say, a butterfly. But links in the chain are not wanting. A well defined link is an animal called *Peripatus*. It is found in most warm climates, and a man turning it up whilst digging in South Africa, say, might wonder, if he wondered at all, whether it was a worm or a centipede. It seems to be a connecting link between the worms and all those jointed-limbed creatures we class together under the name of Arthropoda, the insects, spiders, crabs, lobsters—many thousands of different kinds of each.

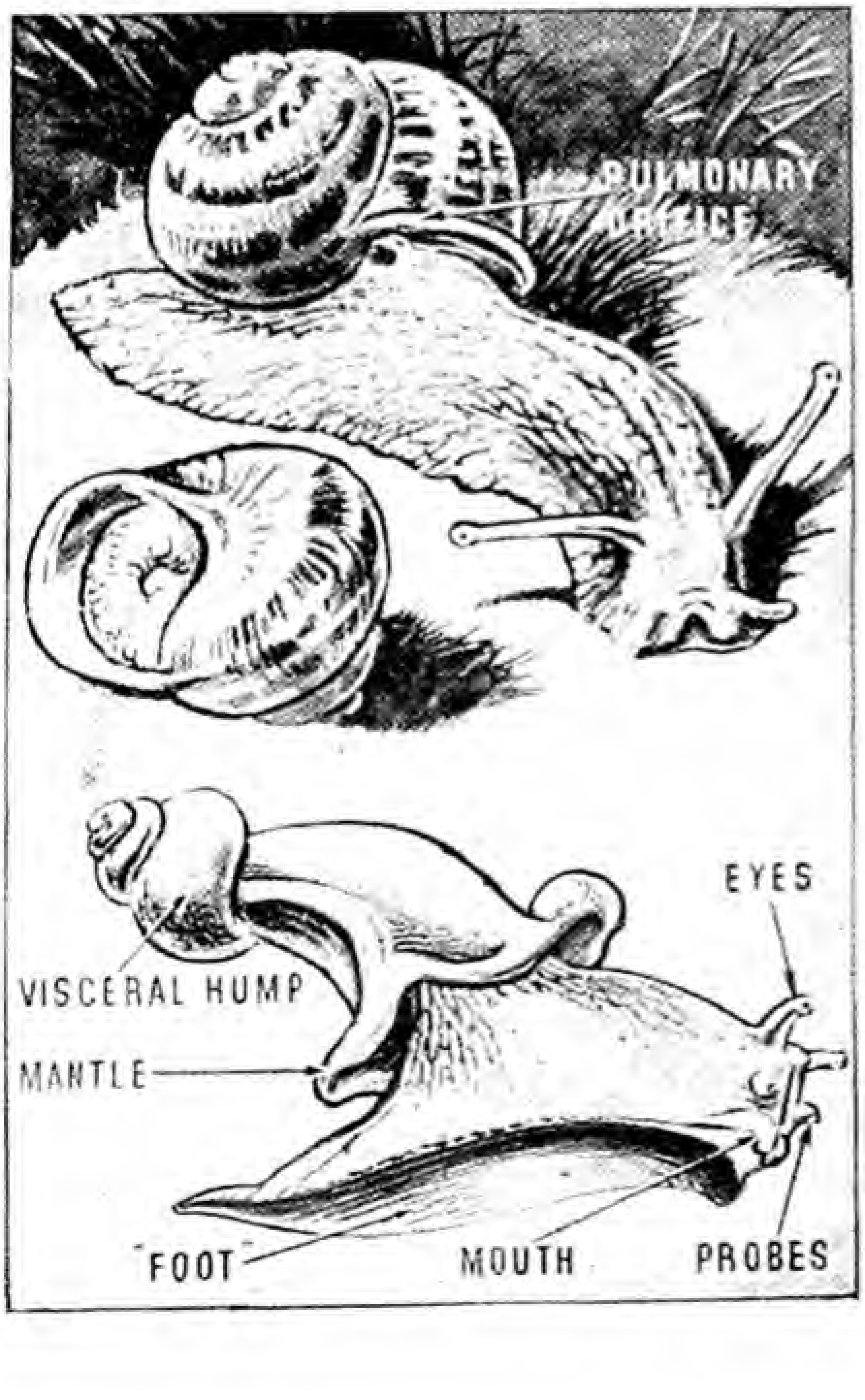
Now, these animals have, in the case of the insects, six legs, the spiders eight legs, crabs and lobsters ten, and the centipedes and millipedes anything from a few score to hundreds of legs. Imagine such an animal getting its legs mixed up or falling over its feet, as sometimes happens to human animals with only two to control. But such a contingency never occurs in these animals. Their many pairs of legs always work in alternate pairs.

Earliest Walkers

Animal movement—propulsion through space—must not be thought of only in terms of modern man. Whilst the worms were groping their way through the sea mud two thousand million years ago, some other animals were finding a very different way of making their worlds shrink. The clams and snails, for example, were using their strong muscular feet to travel in a much more purposeful manner than any worm. A pond snail can plough through stiff mud, relatively speaking, with far more headway than a modern bulldozer. A pond mussel as big as a tank could push the average pier sideways.

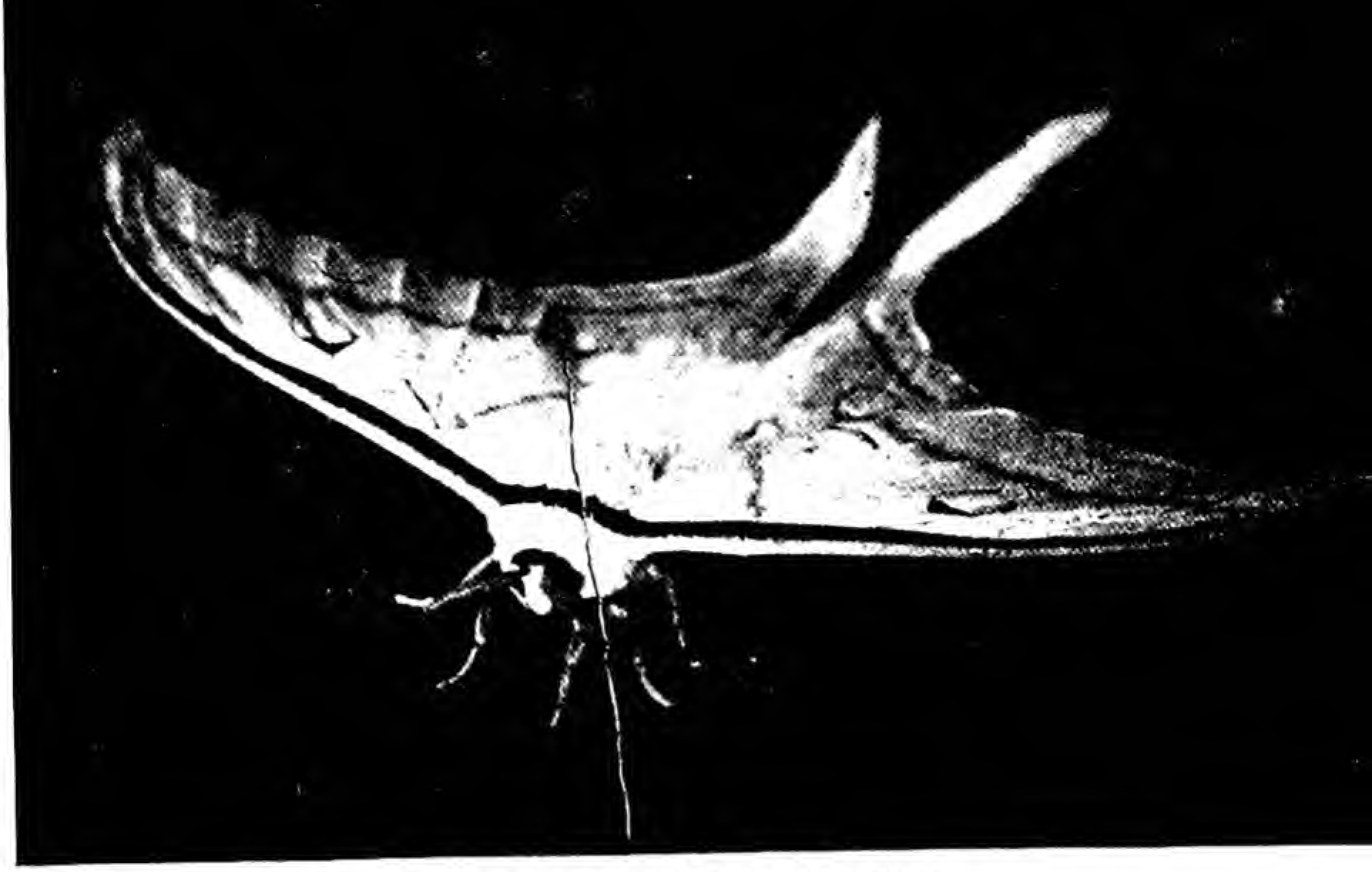
Some related animals, like the mussel or the little fresh-water cockle, *Pisidium*, not only use the foot for progression, but spin with it strings of silk, which attached to some solid object will withstand a gale or a tidal wave. The snail's muscular foot will find a grip anywhere, especially if it is wet. A big snail like *Achatina*, from Africa, can cover a foot in well under a minute.

Side by side with all this progress of long ago, a race of molluscs, called the *Cephalopoda* ("headfooted")—the octopods, cuttle-fishes, squids and ammonites, creatures akin to the pearly nautilus—had mastered the very latest marvel of our age —jet propulsion. These animals breathe by drawing in water through a siphon pipe, passing it over the gills, which take the place of our lungs, and expelling the "exhaust." The pipe is so placed that by breathing hurriedly each expulsion of water



SNAIL'S MUSCULAR FOOT

A snail can push along at a considerable pace with his so-called foot. Actually, the whole underpart of the body forms a muscular sole with remarkable gripping powers.



FLYING BLOSSOM BUTTERFLY LANDING

Butterflies fly in the true sense of the word. This American butterfly (Tropaea selene) has two long projections at the back of the wings which facilitate downward flight.

forces the animal backwards at a considerable pace. An octopus, for example, can shoot through the water backwards at about four miles an hour. A lobster, more nearly related to the insects than the octopus, achieves the same end by simply snapping its tail. The force of the water so ejected sends the animal backwards. A lobster is so well supplied with sense organs that it can reverse like an arrow into some sheltering rock crevice, with an accuracy that might well excite the envy of many a car driver.

In this attempt to trace animal movement chronologically it would seem that the mastery of the air was first achieved at its very latest during the formation of our coal beds about two hundred and fifty million years ago. The problem that is now shaping our lives was first solved by the insects. The fossil evidence of early insects is very incomplete, but it is sufficient at least to hint that the first flying insects had three pairs of wings. They were doubtless clumsy structures, no more than amplified scales, outriggers as it were from the general body structure.

With these, the insect planed from point to point, usually in a downward direction, but doubtless often aided by the wind. However, mere planing was soon discarded for well directed flight. Cockroaches and beetles have but one pair of fully manageable wings. The upper and larger pair are mainly wing covers, but still enable the owner to take flights of varying length, as the wind permits. Very different is the flight of the butterfly where both wings are under direct control.

First Flying Animals

Flight has indeed been achieved by many groups of animals in greater or lesser degree, and by the most dissimilar means. Long after the insects came into being, the reptiles achieved flight of a kind. Their greater triumphs were in the so-called Cretaceous period, about one hundred million years ago. At that time, when the dinosaurs were an established order on land, and the sea teemed with giant lizards, turtles and sea snakes, the reptiles ruled the air. The pterodactyls, or wing-fingered reptiles, swarmed in all parts of the world. Remains of them, ranging in size from those of a thrush to animals with a wing-spread of eighteen feet, have been found even in the British Isles.

A typical pterodactyl—or winged dragon to use the popular and misleading name

—must have looked somewhat like a plucked chicken with a very long and toothed beak, and a huge pair of skinny, bat-like wings stretched on either side between the ankle joint and the tip of the fourth finger. This finger was enormously enlarged—sometimes for a yard or more. The remaining fingers were normal, and, one assumes, used for climbing. There were usually four workable toes, either a long tail or the merest vestige of one. The eyes of this strange creature were big.

Mysterious Departures

Such was the flying dragon of a kind that must at one time have swarmed like rooks about the cliffs and waterways of Britain, quite apart from their presence in more exotic scenes. That these creatures should have become extinct so suddenly is as great a mystery as the utter and equally sudden extinction of the dinosaurs. It is to some extent more surprising, for the pterodactyls must have lived largely, if not exclusively, on fish, and where fish are, the fish-eating creature can generally pick up a living. But the pterodactyls vanished, and, one fancies, only the naturalist regrets their departure.

The nearest approach to flight enjoyed by any living reptiles is seen in the fringed gecko, the flying lizards and snakes of Borneo and Malaya. In these creatures, flight is merely a matter of gliding, achieved by a sudden expansion of the ribs, which stretches the skin so tightly as to form a sort of kite. By this means the animal travels on the wind, usually in a downward direction. It is far less directable than the flight of the gossamer spiders. These creatures can mount to the top of a grass blade, and let loose from their spinnerets three or more strands of silk. The strands catch the wind and waft the spider to fresh hunting grounds. When the spider wishes to alight, it simply furls sail by winding in some of its silk.

Flying Creatures of the East

The East, for some reason, is the world's principal habitat of gliding animals. From Madagascar, Ceylon, India, the East Indies, China and Japan come the weird flying frogs. These have all their digits, four fingers and five toes, so amply webbed that they form very serviceable supports on the heavy, moisture-laden air when the frog takes a literally flying leap from one treetop to another.

An almost exact replica of this is seen in the weird cat-size fruit-eating lemur, or cobego, of Malaya, but its planes are augmented by great sheets of very elastic skin extending from the little finger of either hand to the corresponding great toe. Various flying squirrels from Borneo and Africa are similarly fitted with planes, but they are differently arranged in the two races.

In the African squirrels, the plane is supported on a finger-long extension of the elbow joint; in the Asiatic, from a similarly grotesque development of the wrist; and a few kinds of phalangers—Australian opossums—have a very similar apparatus running from chin to wrist and from wrist to ankle.

Flight and Man

Bird flight has been the subject of many volumes. It fired man's imagination from the first until, after innumerable tragedies—crystallized in the legend of Icarus—he came into what he now largely regards as his own. The bird's wing, it may be said, is simply an arm, fitted with feathers, and feathers are split-up scales, one in substance with skin, horn and hair. Early human efforts to achieve flight foundered owing to their slavish modelling on the flight of birds.

Only when the motive power of the flying machine, the engine, was made a separate body from the air-resisting structure, the plane, did human flight become practicable. A bird's wings have their chief motive force in the muscles attaching them to the breastbone. In the extinct flying dragons and modern bats, the breastbone is poorly developed, but in such birds as the swallow and humming bird it is exceedingly light in relation to the engine built to carry it. It has been estimated that for a man to be able to fly like an eagle he would need feather-clad arms at least eight feet long, with a breast-

LIMBS OF SOME FLYING ANIMALS COMPARED

Limbs of the so-called flying animals are adapted in various ways to enable them to glide through the air. Four of the bat's fingers have become elongated and webbed to form a membranous wing; only the thumb is free. Flying frogs have fingers and toes webbed.

bone extending to his knees and protruding a good two feet beyond his chin.

From flight to swimming may seem a somewhat violent transition but, fundamentally, the two forms of progress are much the same. The water offers a denser medium, that is all. The swimmer, like the airman, must find a way to thrust it behind him, to use it as a lever.

How Fishes Swim

By all the evidence, i.e. of fossil records, vertebrate life was well established in the water millions of years before it invaded the land. The first fishes and half fishes, like the lampreys, swam in a worm-like manner, with sinuous movements of the body, and later fishes, like the skates and rays, attuned to living close to the sea floor, use this sinuous movement not from side to side but in an up and down direction of their great pectoral fins or wings. Watch these fins in a skate, and you will see they reproduce the action of wind-pressed waves, racing shorewards. The higher fishes like the cod, mackerel or tunny, use their paired breast-fins very like oars, or hands, but largely for backing or turning corners. The principal motive is supplied by the tail, just as it is in the crocodile, some aquatic lizards and worms, and the beaver and musk-rat.

The beaver, however, offers an interesting example of the same parts of the body being put to the same uses by quite different animals. The musk-rat's tail is flattened like that of a fish and is "waggled" in the same way. But the beaver's tail is compressed horizontally like that of a whale, porpoise or manatee and gives a rocking-horse quality to the owner's mode of swimming. The beaver, be it noted, is first cousin to the rabbit, the whale, a flesh-eating beast once, has taken to the water, and the manatee is a not too distant relative of the plant-eating elephants.

All other mammals, even such adept swimmers as the otter, polar bear and sea-lion, may be said simply to walk under water. They largely reproduce the same movements of the limbs as upon land. The webbing of the otter's and sea-lion's limbs is merely a natural outcome of long sojourn in a particular environment. Both animals are essentially the same under their skins. The polar bear has enormous staying power, but is a slow and clumsy swimmer. It relies almost entirely upon its fore paws. The hind are used for steering and braking.

The very few birds that can be truly said to swim under water do so by one of two methods. The cormorants and shags force themselves through the water by a terrific exertion of their extravagantly webbed feet. The penguin, and to a lesser extent the guillemot and razorbill, however, literally fly under water. The penguin has, for its size, a heavier skeleton than any other bird, and this, combined with its ample lungs, enables it to take underwater flights of many minutes with no appreciable effort. Its heavy feet, so clumsy upon land, aid it in turning in half its own length whilst travelling at full speed.

Prehensile Tails

Before considering normal quadrupedal progress, and the possible steps taken to achieve our own accepted carriage, it is worth while to note how almost every part of the mammalian make-up except the head, has been utilized as a means of travel. The head, indeed, always remained in command and dictated movements. Just as many aquatic creatures rely on their tails for engine power, so, ashore, some few animals have put the tail to far greater use than as a mere fly whisk or balancing pole. The harvest mouse is the only mammal in Britain to possess even a partially prehensile tail, but in other and more densely wooded lands, that useful appendage has been trained to the service of a fifth hand. Familiar examples are the spider, howler and woolly monkeys of South America.

But quite as efficient are the prehensile tails of the American opossums, a variety of Australian marsupials, the various tree porcupines, and two semi-carnivorous creatures, the kinkajou or honey-bear of Brazil, and the far-eastern cat-bear or binturong. The honey-bear's tail is not only a very helpful climbing organ in the way of normal progress, but it provides a handy means of escape if the animal is

BIRDS IN FLIGHT

The wing of a bird is really a modified foreleg and corresponds to an arm in a man, which it resembles closely in structure. But in a bird the bones of wrist and palm have become united and only three tiny fingers remain. The wing feathers (quills) are long and strong and overlap to make a broad surface to push against the air. On the upward stroke the feathers separate slightly to allow the air to pass through, thus lessening the pressure. The under surface of the wing is concave, an important factor in flight. There are various types of flight. The gull (top left) is simply gliding through the air; the Australian seagull (right) is using his wings in a downward swoop while the gannet (top right) is braking preparatory to landing.

SPIDER MONKEY

Spider monkey hanging by its long prehensile tail, which serves it as a fifth hand and prevents it from falling as it swings itself from tree to tree. The tail is extremely sensitive and has considerable gripping power.

attacked by bees. The kinkajou often hangs head downwards by its tail to rob a hive and, overstaying its leave, brings out the swarm in full fury. When even its dense hair and tough skin seem in jeopardy, it actually climbs up its own tail and so escapes to the branch from which it was suspended, and the safety of denser leafage.

It is tolerably certain that man evolved from some arboreal stock, although, as Darwin pointed out (and has been persistently misquoted), not necessarily from monkeys. The more generally accepted view today would seem to favour some branch of the ape stock. That he came to walk erect gradually is certain, and that not without an effort, scarcely less so. The gibbons of Malaya and the Far East habitually run along tree branches whilst in an erect attitude. The faster they move, the more easily the upright pose is maintained. It is significant that in the Philippines lives a race of jungle folk who habitually make long journeys via the tree tops. They use horizontal branches as roadways and maintain equilibrium by means of a balancing pole, just as the circus artist makes his way over the tight rope or slack wire.

No phase of terrestrial travel, indeed, has been left untested by the inquiring mind of the mammal. The mole can almost fly through loose, dry soil with the speed of a penguin under water. The mole probably has the most powerfully built shoulder muscles, for its size, in the world. It has been estimated that a mole as big as an ox could bore a Channel tunnel in a week. Leaving this improbable proposition, it is interesting to note that the world's most proficient burrowing animals all approximate to the same cylindrical formation and powerful development of the fore part of the body. Examples that readily commend themselves are the mole cricket, the various burrowing prawns, such as *Gebia*, and even the now rather out-of-date basset hound, originally bred, and once largely used, for negotiating badger earths.

It is a matter of much less than a century—indeed since the early days of the cine-camera—that the precise manner in which quadrupeds move has been really understood. By means of cine-photography, movement can be studied and analysed, and quadrupeds are now grouped into two classes, rotatory and diagonal walkers.

Man may flatter himself that he is a biped, but he swings his arms with alternate legs, the normal habit of diagonal walkers like the monkey, bear and many other quadrupeds. The dog, and many cud-chewers such as deer, elk and antelope, on the other hand, employ the rotatory gait, i.e. the feet strike the ground in regular succession, starting off with the right hind and passing clockwise via left hind, left fore and so to the right hind again. In the dog, at least, the sequence may equally well be anti-clockwise, there seems to be no hard-and-fast rule. The bear and many allied animals have always one foot on earth, but when horse and dog are going "flat out" there is a moment in each stride when all four feet are clear of the ground.

In none of the non-arboreal quadrupeds

does the tail play any important part. But in the few fishes that come ashore and make brief excursions overland it is a very important factor. The anabas, or so-called climbing perch of the Far East, for example, not only scrambles along on its breast-fins, but by bending its tail against some stable object and then suddenly straightening out gives itself a very appreciable forward thrust. The little gobies, known as mud skippers, that swarm in the paddy fields of Malaya, use their tails so that they jump with the agility of frogs.

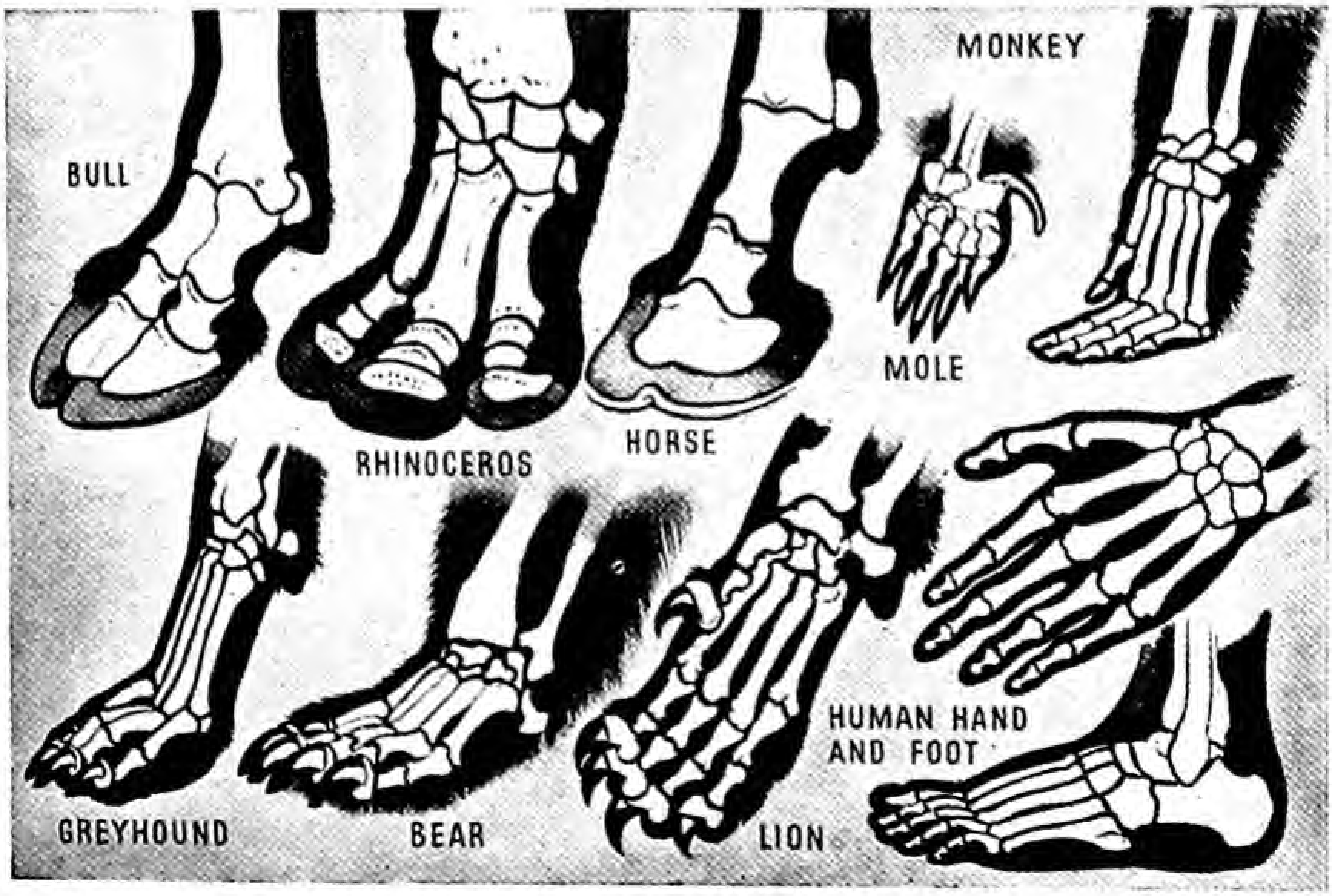
Bipedal walkers, when they use the tail at all, use it as a balancing organ, swinging it to the same side as that of the out-thrust leg. So moves the little frilled lizard of Australia that habitually runs on its hind legs when in a hurry.

One method of progress that falls into no particular category remains to be mentioned, the curious stride of the leeches, looper caterpillars and a few other creatures. These animals have sucker pads at the hinder end of the body and they move by alternately stretching forth the head end, taking a fair grip of territory with legs or mouth, and then, by humping the body, tail and head literally meet. Some leeches can travel thus at a fair speed, with a stride of as much as half a hand's length.

Finally, a word on speed, one of the watchwords of our restless age. Here again, modern machinery has reduced what was once vague eye measurement to hard facts. The stop-watch and the speedometer have given us some very interesting statistics of animal movement.

The cheetah, or hunting leopard of India and Africa, holds the world's record for a quadruped over a short distance, say, one hundred yards. It can cover this at a rate of seventy miles an hour, about half that of the fastest train. Next in order come the pronghorn antelope and gazelle, sixty miles an hour, the rabbit forty-five, wild ass forty, whippet thirty-five and emu thirty-one.

The air, offering less resistance, has enabled some birds, such as the golden eagle and vulture, to make extraordinary spurts of from ninety to one hundred and twenty miles an hour and even quite small



FEET AND HANDS

Limbs of mammals are adapted in various ways to suit their mode of life. Hoofed animals have long slender legs for speed, carnivorous beasts padded feet for silent approach to prey.

birds, like the crossbill and flycatcher, can make scarcely less surprising speeds in relation to their size.

Water, densest of mediums supporting life, offers comparatively modest records, even on the part of powerful animals. The salmon's best speed is estimated at seven miles an hour against the ten miles an hour of a submerged submarine. The record is held by the swordfish with sixty miles an hour. No whale can exceed thirty miles an hour.

Snakes, to the careless onlooker, seem to glide imperceptibly at lightning speed, but their rate of progress is at best relatively slow, and much depends upon the surface covered. A snake moves by thrusting the edge of each abdominal scale against the earth, and then by a powerful muscular effort levering itself forward. Moreover, a snake quickly tires, by reason of the exertion needed to force its limbless length along. Continuous friction acts as a brake. Impressive as the speed of a serpent may appear, it seldom if ever exceeds three miles an hour.

Much research yet remains to be done concerning the rates and methods of progression in animals, and the work to date has often helped materially in solving problems of human transit.

That extraordinary and incomparably complex telegraphic system permeating every part of the human body, loosely summed up in such words as nerves, feeling or sensibility, is often all too painfully apparent. Most of us also have a sort of a cut-and-dried conception of the chief centres of this sensibility or feeling. The head is obviously the main centre. We regard the tongue (quite erroneously) as an organ of taste, the eye as a means of vision, the ears as our chief, if not only organ of hearing.

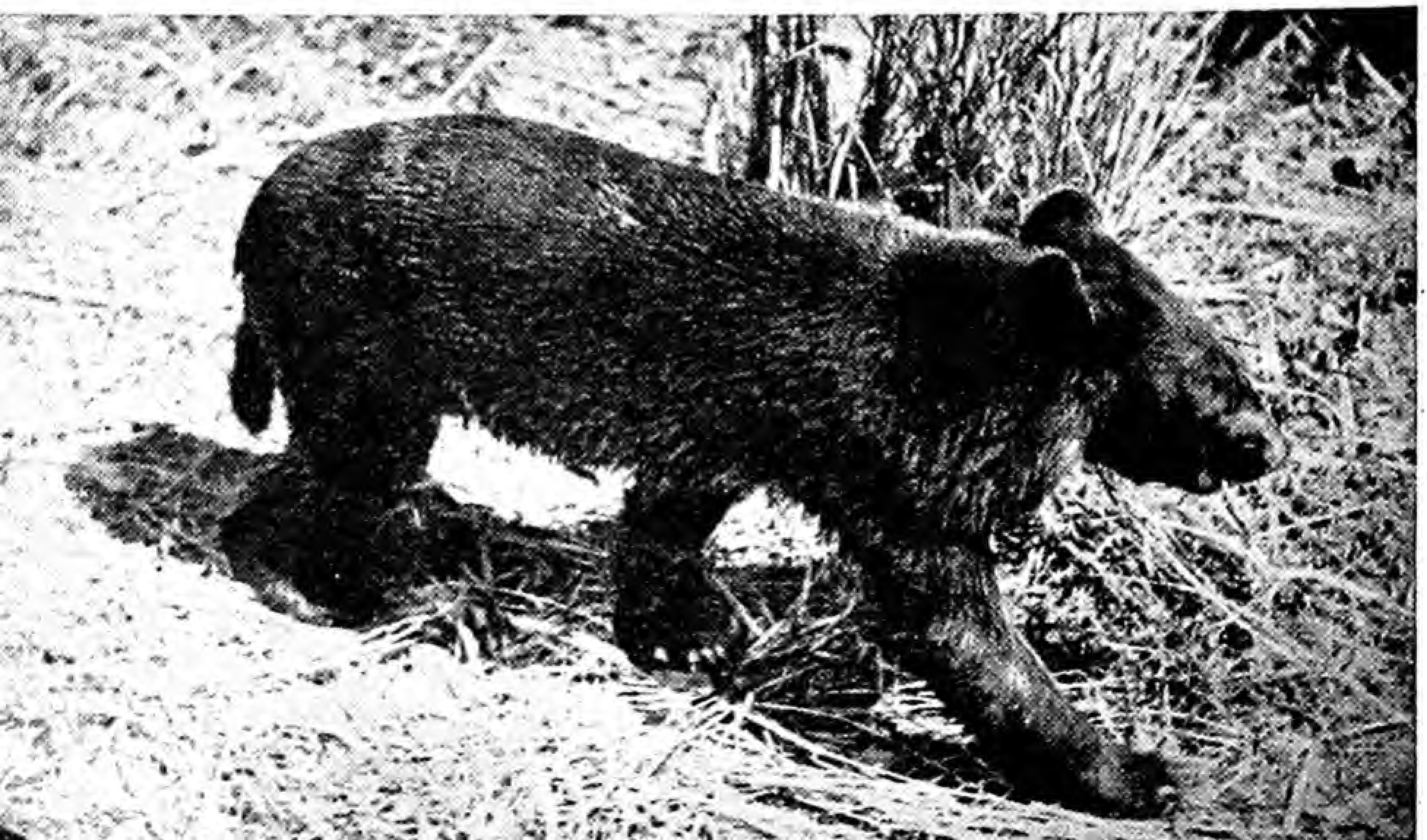
But when we take a wider survey of the world around us, and consider not ourselves, but the lower animals, all of these age-old preconceptions go by the board. We are reminded of the elder Mr. Weller, when, speaking of that legal luminary Mr. Solomon Pell, he sagely observed:

"A limb o' the law, Sammy, as has got brains like the frogs, dispersed all over his body, and reachin' to the wery tips of his fingers."

Wide of the mark as this statement was, it was not so very wide. Travelling down the animal scale we see apparent topsy-turveydom the order of the day. Quite

DIAGONAL WALKER

Animals which, like the bear, put the front foot down alternately with the back foot are called diagonal walkers. A bear also differs from many quadrupeds in walking with the whole of its foot flat on the ground. Most animals walk on the toes only.



WORLD'S SWIFTEST MAMMAL

Cheetah, or hunting leopard, holds the world's record for speed among mammals. It has been known to cover short distances at the amazing rate of seventy miles an hour.

common animals use the tongue chiefly as a guide in the dark, or as a fishing rod. Others carry their ears on their knees and elbows; taste organs can be planted between the shoulders, eyes carried in the most unlikely places. As for the great centre of feeling—the brain, it can be so lacking that an animal may be cut into many portions and experience far less inconvenience than a man tripping over a door mat. That "heart in the mouth" feeling has no meaning at all for the great majority of invertebrate animals.

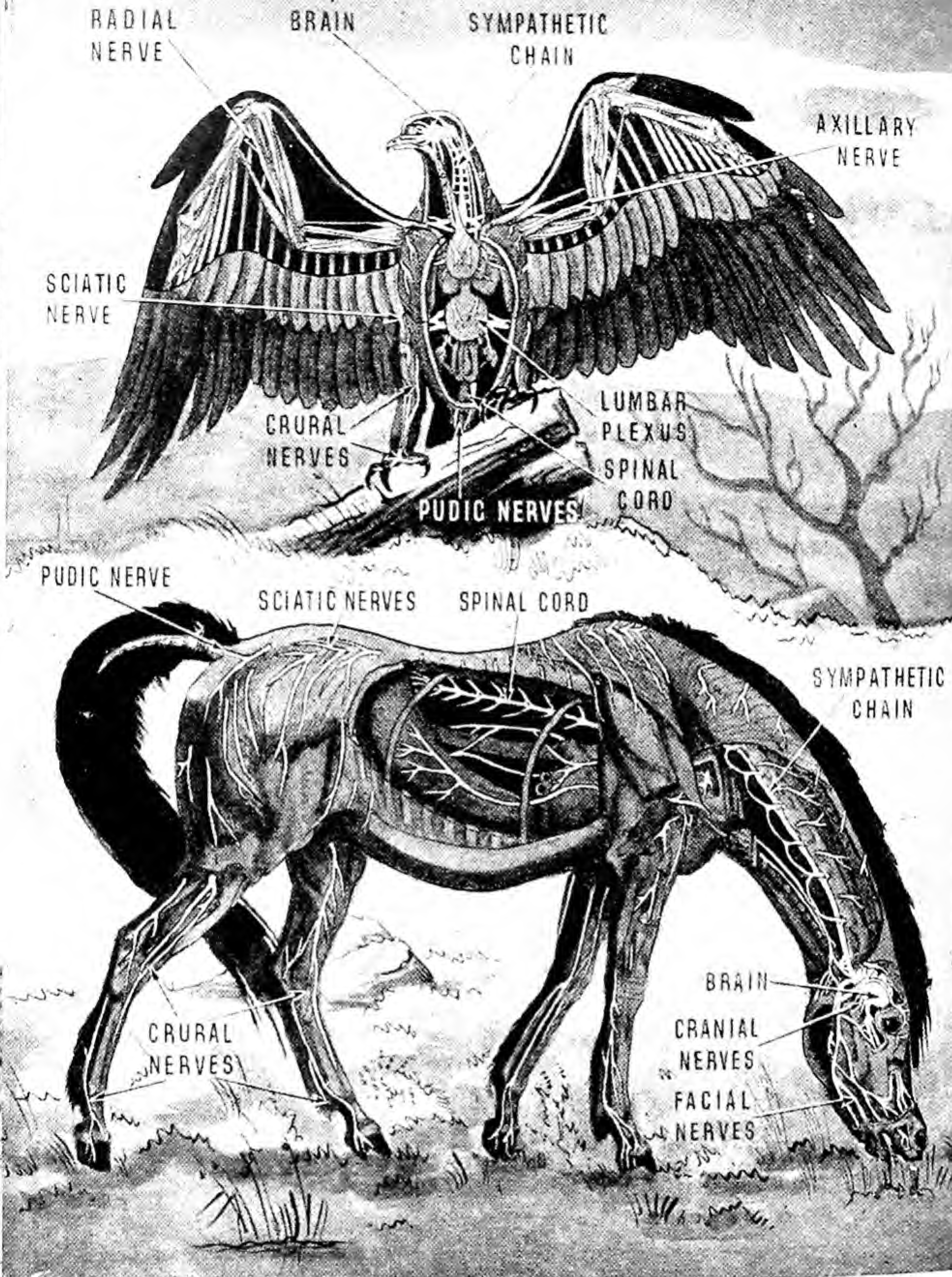
Centres of Sensitivity

Nerves, by which all animals feel, are a special kind of highly-sensitive tissue that in all vertebrates, mammals, birds, reptiles, amphibians and fishes culminates in a mass of the same material, which we call the brain. This mass is situated in the head. But in most of the invertebrates, even when a head is present, the brain is no more than a minute joining up of the nerve threads. It leaves no room for thinking. The complex behaviour of insects, their often wonderful nest-building for example, cannot be said to have its root in thought. The insect appears to be a mechanism wound up to perform certain actions. It cannot move outside of its narrow role, so to speak.

If we study some invertebrates lower in the scale, the molluscs—snails or oysters, or such creatures as the spiny-skinned animals, the sea-urchins and starfishes—we shall find there is not even a definite centre of nervous control. Instead there are a number of such centres. In the starfish, the main nerve centre takes the form of a circular track. If one, or even several arms are torn off, the rest experience no pain nor are they even incommoded. The break is soon healed, and the dismembered limbs go their way, finding and assimilating food. Yet a starfish is sensitive in many ways, to touch for example, and even to light.

If we consider the different well-defined senses, that of sight is the first to suggest itself. The normal person relies upon it more than on any other sense perhaps to apprize and appreciate the world around. But sight is a sense with a wide range of quality. Some of the single-celled animals that throng the waters, both salt and fresh, have nothing that can be called eyes. Yet they are often very sensitive to light. Higher in the scale—the worms have special organs that respond to light, but scarcely answer to eyes, as we understand them. In the molluscs, however, creatures much lower than the insects and other jointed-limbed animals, eyes attain a wonderful pitch of development, and are carried in a variety of ways. Some snails, like the common pond snail, *Limnaea*, or the limpet, have the eyes placed at the base of the tentacles, or horns.

In most of the land snails they are planted at the tips of extensible horns that when not in action can be closed down by being pulled inwards very like the fingers of a glove. The two-shelled molluscs, such



NERVOUS SYSTEMS OF HORSE AND BIRD COMPARED

The nervous system in vertebrates is made up of two related systems, the somatic nervous system and the sympathetic system. The first consists of the brain, the spinal cord and nerves given off from both of these. Vital functions of the heart, lungs and other organs are regulated by the sympathetic system.

as the oyster and mussel, are as often as not without definite eyes. But the scallop's show as vivid jewel-like beads spread along the outer margins of its general body covering, the mantle. The highest of all the molluscs, the octopods and cuttle-fishes, have huge paired eyes with hard crystalline lenses. In some countries, such lenses are often used for human ornament and were popular counterfeit eyes in the mummies of ancient Egypt.

Many-faceted Eyes

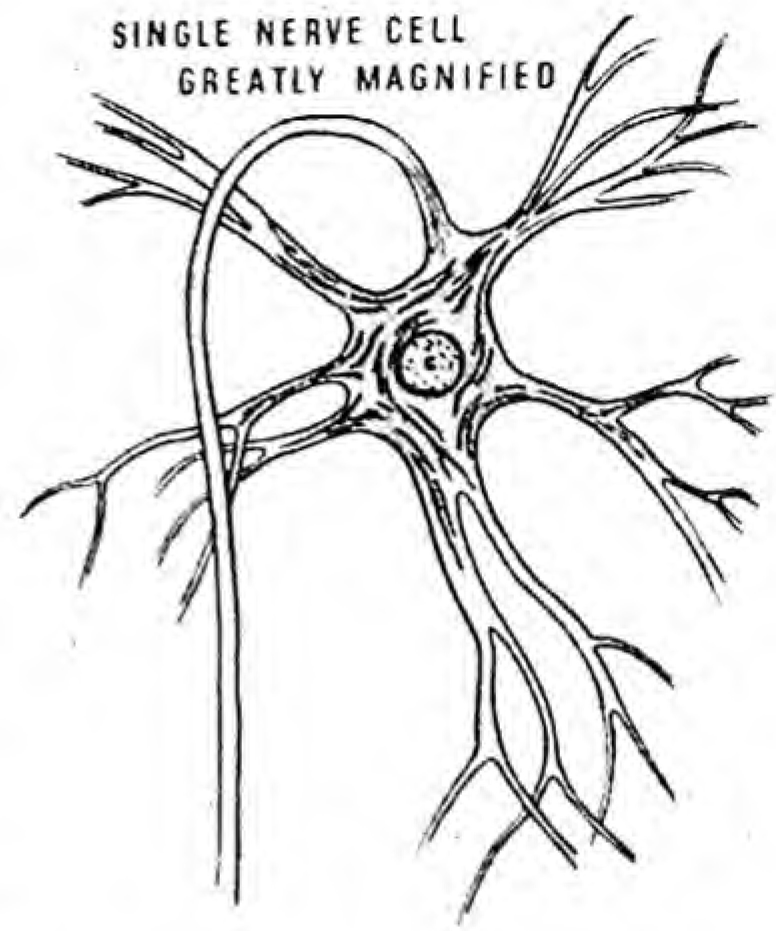
Amongst the jointed-limbed animals already referred to—the insects, crabs, lobsters, spiders and so forth—we often meet with a totally different sort of eye. The eye of a house-fly, for example, though built on the same general principle as every other eye, i.e. a lens which projects the view before it on to a sort of screen, has its surface divided up into a great number of six-sided plates. In many butterflies there may be some thousands of such plates. But the brain, or chief nerve centre, does not necessarily receive thousands of images. Rather it may be compared to looking at the world through a latticed window, each little pane of which gives its small view of the world and all summing up to make a perfect whole.

In some invertebrates, notably the king crabs (*Limulus*) of tropic waters, there is the strange organ known as a median eye—placed centrally between the eyes proper. Surprisingly we meet an organ in a similar place, atrophied from disuse, as a survival in a famous vertebrate, the tuatara lizard of New Zealand. This little reptile, rigidly protected by law, is the last representative of a group which had its heyday at least seven hundred million years ago.

Disposition of Eyes

But in the great mass of vertebrates we meet eyes, readily understandable paired organs, much like those with which we view the world, albeit they are disposed in an endless variety of ways according to their owners' needs. Often there is a third eyelid, the nictitating membrane, which can be drawn across, not downwards or upwards to cover the eye. Eyelids are absent in fishes, possibly because being immersed their eyeballs have no need of lubrication. In other vertebrates, the eyelids not only cover the eyes from the light when needed, but serve to spread evenly the fluids that continually wash the eye and prevent it from drying up as it would otherwise do very quickly. One group of fishes only, certain of the sharks, for example the common spotted dogfish, can close the eyes, a faculty which has caused it to be regarded with awe by some seafarers. Cornish fishermen will put dogfish overside with something very like reverence.

The eyes of fishes are placed in a vast number of ways. Usually there is one on either side of the head, but the skates, swimming on one side only, have both placed on top. The skate is really only a flattened dogfish. There are many intermediary forms, as for example the common monk or fiddle fish. But in the more popular flat fishes—plaice, turbot, sole and so on—the young fish is not hatched like a skate, prepared to swim on its flattened underside with both eyes set on the upper or coloured surface. Instead, it comes into the world much like a round fish, as

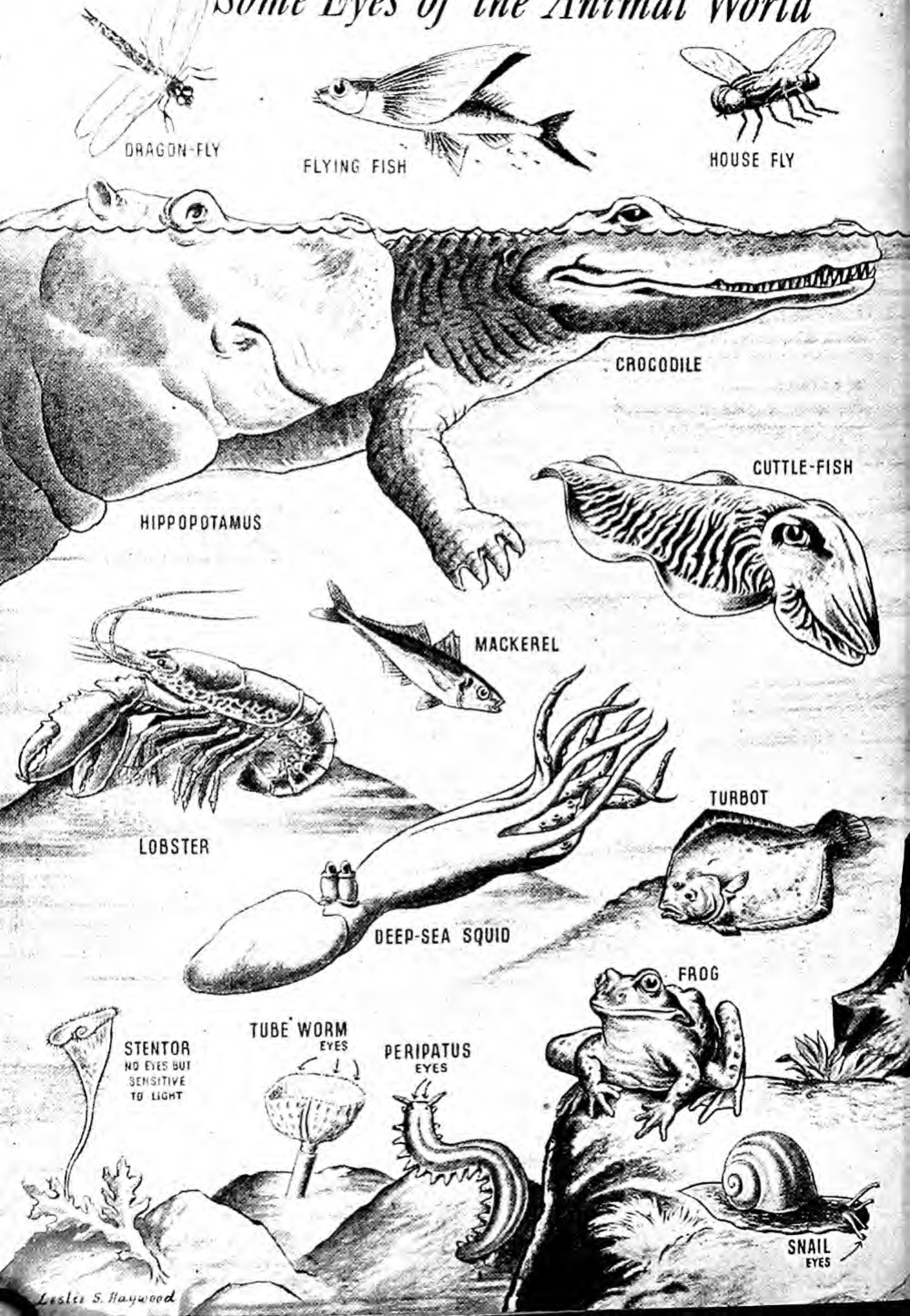


MAGNIFIED NERVE CELL

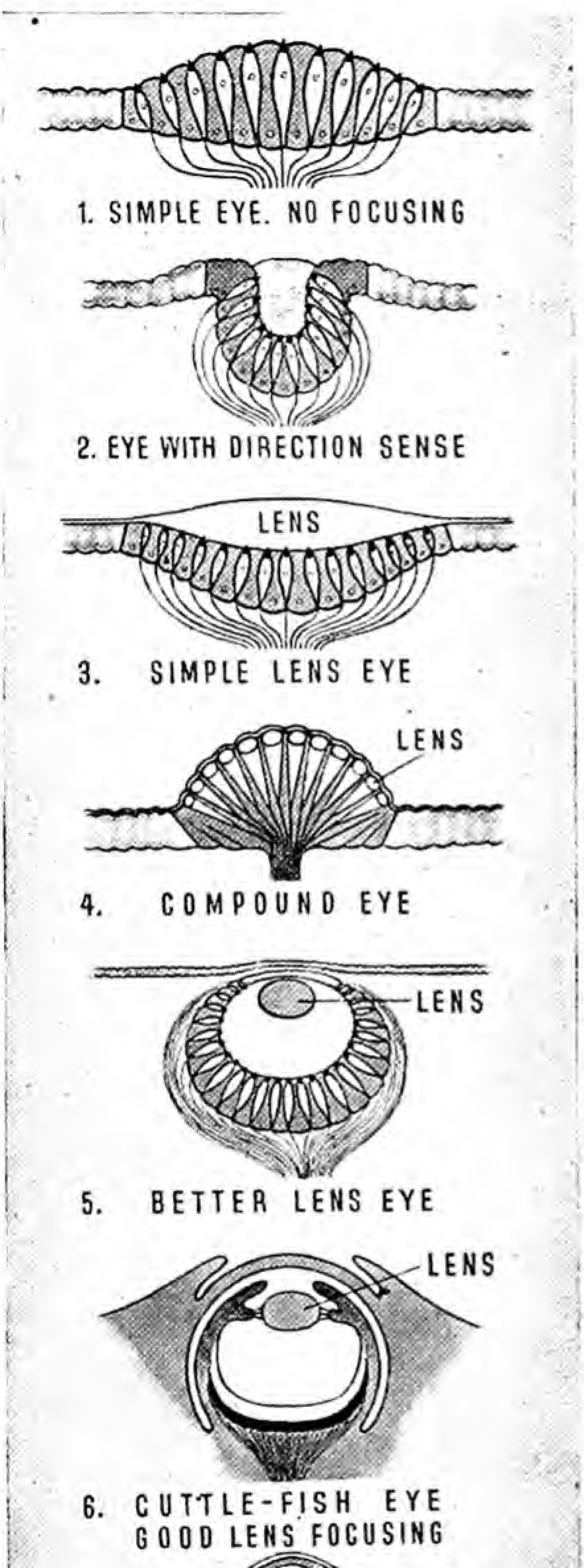
Nerve cell from the brain, the centre of the nervous system in vertebrates. Nerve cells transmit messages from the brain to all parts of the body.

HOW THEY SEE

Some Eyes of the Animal World



EAGLE
STALK-EYED FLY
TARSIER
OWL
ANTIGONIA
MONKEY
ABBIT
MOLE
PIDER
TIGER
NOTE:-THE SIZES OF THE ANIMALS ETC. BEAR NO TRUE RELATION TO EACH OTHER



SIMPLE AND COMPLEX EYES

Eyes vary from the simple type with no focusing power, found in some of the worms and lower invertebrates, becoming ever more complex in the ascending scale of life and culminating in the human eye, which sees more than any other, except perhaps, a bird's.

fishermen call them—the cod, mackerel, and so forth. Like these fishes, too, the little plaice swims " on edge " in the sea.

But within a few weeks or months after hatching it sinks down from its nursery playground in the upper water layers towards the sea floor, at the same time tilting to one side. By the time it comes to rest one side only, the coloured side, is exposed to the sea. The other lies for ever pressed to the sand. During this process a remarkable change overtakes the eyes. The eye that would otherwise be undermost slowly creeps round the upper edge of the fish's head, until it joins its fellow. Finally, the two eyes lie side by side, a marvellous adaptation to altered needs.

Eyes that Work Independently

Like the eyes of the famed chameleon the eyes of most fishes work independently. In all birds and mammals they move in unison. A fish, therefore, can cover a remarkable range of vision, and being able to look in two opposite directions simultaneously, has an ideal command of possible eatables as also of approaching foes. The migratory eye of flat fishes may move to the right or left side, according to the species. This unique adaptation was discovered by the famous Francis Tresilian Buckland towards the end of last century.

The young of some deep-sea fishes, like those of some squids and tropical crabs, have the eyes mounted on stalks as long as any snail's. In the little tropical mudskipper they are poised merely on short pedicles. Fishes' eyes may be minute, as in the Cuban and other cave fishes, or enormous like those of the bream. One very remarkable little tropical fish known as Anableps, or the four-eyed fish, actually has the pupil split, so that, swimming always at the surface of the water, it enjoys bi-focal vision. It can with equal facility spot fly

CLOSE-UP OF EYES

At the top (left) is a bird's eye showing nictitating membranes. Above is an insect's face, magnified. It has two large compound (many-faceted) eyes with three small simple eyes in the middle. A chameleon's eye (left) has exceptional focusing powers. The eye is almost covered by a circular fold of skin which leaves only the pupil visible.

larvae crawling on the stream bed, or the perfect insects winging their way overhead.

Birds, as will have been pointed out elsewhere, are but glorified reptiles. In their egg-laying habits, general skeletal structure, retention of scales and covering of feathers, which are but scales split up—they declare their reptilian ancestry. Most, if not all lizards, have the eye strengthened by a ring of overlapping bony plates.

These rings can be seen with ease in any bird, and in some they reach a most extravagant development. The sclerotic rings (as they are called) of an owl's eye are so big that in an eagle owl they may reach the dimensions of an average pill-box and be of vastly stronger substance.

Even in mammals, the eyes show considerable diversity of position. In ourselves and next of kin, the apes and monkeys, both eyes look to the front. But amongst all the grazing animals, expectant as they are in the wild of perpetual attack from behind or either side, the eyes occupy much more lateral positions. A backward glance is possible without, as in ourselves, an appreciable movement of the head. Despite their deep orbits, most mammals' eyes are surface structures, with little to obstruct a clear view ahead. In some desert-dwelling apes, however, like baboons, they are deep-set beneath beetling brows, probably as a protective measure from the glare of the sun. A baboon, like an eagle, depends upon a continuous downward scrutiny of its world in order to discover food.

Some few mammals have the eyes set high up in the head—almost in little towers of bone—periscopic eyes. This is a characteristic of aquatic creatures. It is seen at its best in the hippopotamus, which in this regard imitates two creatures much lower in the scale, the crocodile and the frog. The largest of all mammalian eyes, in proportion to their wearer, are those of the spectral tarsier, a tiny nocturnal lemur of Borneo. The smallest eyes, in relation to the animal, are those of the whale, but other sense organs apparently compensate for any poverty of vision.

Second-prized Sense

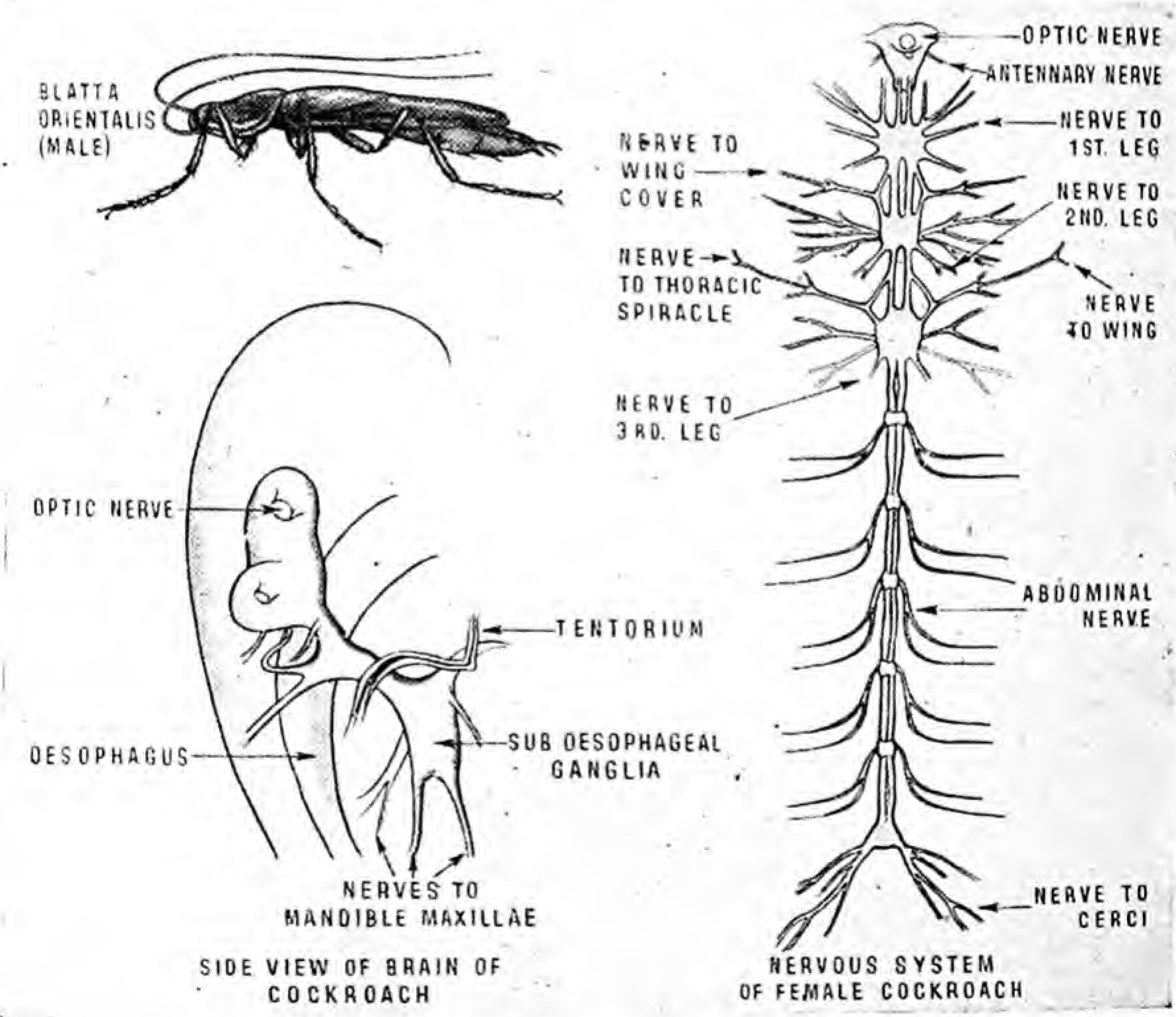
Most humans probably cherish hearing next to eyesight as the most precious of their senses. To the blind it is all in all, and to many others hearing is the faculty by which they can apprize and enjoy some of the arts. Ears vary much in their complexity of design, but suffice to say, here, that the ear proper, i.e. the internal ear, is, with all its intricacies of ossicles and other features, reduced in essence to a stretched membrane—a drumhead. Sound waves of any kind striking this drumhead are carried by vibration to the brain.

To most of us, however, the word "ear"

invariably calls up the external ear—a mere sounding board or receiver, standing out from the head and fashioned to catch all airborne messages in its vicinity. The degree to which mammals rely on sound for their livelihood or safety may be gauged by the size and shape of their external ears. In the tunnelling mole, or shrew, and the deep-diving whales and seals they have virtually vanished. But in the plains or jungle beasts, elephants, horses, deer, dog, rabbit, etc., they are often enormously developed. Usually these ears can be swivelled by means of powerful muscles, to sweep through half or more of a circle.

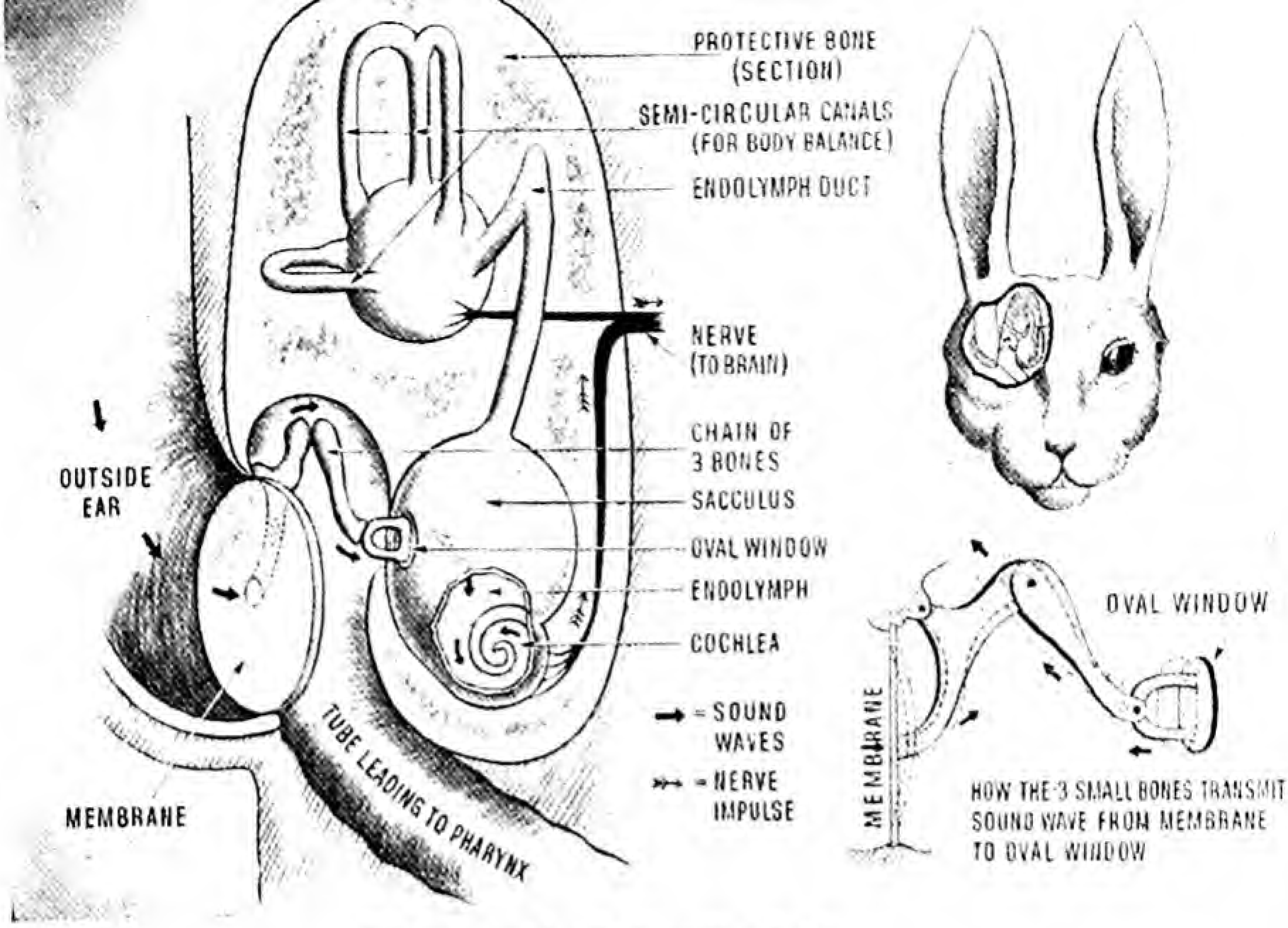
Remnants of these muscles still remain to man, but they have almost wholly atrophied from disuse—a tribute to how much more reliance man places on the faculty of sight. Only a very few persons can even twitch their external ears. Once the ear-drum is destroyed little can be done to offer a substitute. But of recent years various devices may in some cases of deafness give the sufferer at least an indication of noises, i.e. sound waves in his vicinity. Vibrations of a kind may be felt with other parts of the body, notably, it is claimed, by the back of the neck.

Birds have their external ears covered by a sheaf of feathers, probably as a protection against dust, but they are nevertheless present and can easily be seen in any bird by gently blowing against the feathers at



NERVOUS SYSTEM OF AN INSECT

The nervous system and brain of a cockroach are typical of most insects. There is a double nerve cord with nine ganglia, from which nerves radiate to different parts of the body. The chief sense organs are the eyes, the antennae and the maxillae.



MECHANISM OF RABBIT'S EAR

Essential part of the ear is the inner ear which consists of two hollow bags connected by a Y-shaped tube, the endolymph duct. The cochlea is a snail-shell shaped bone lined with cells covered with tiny protoplasmic threads which perceive sound waves.

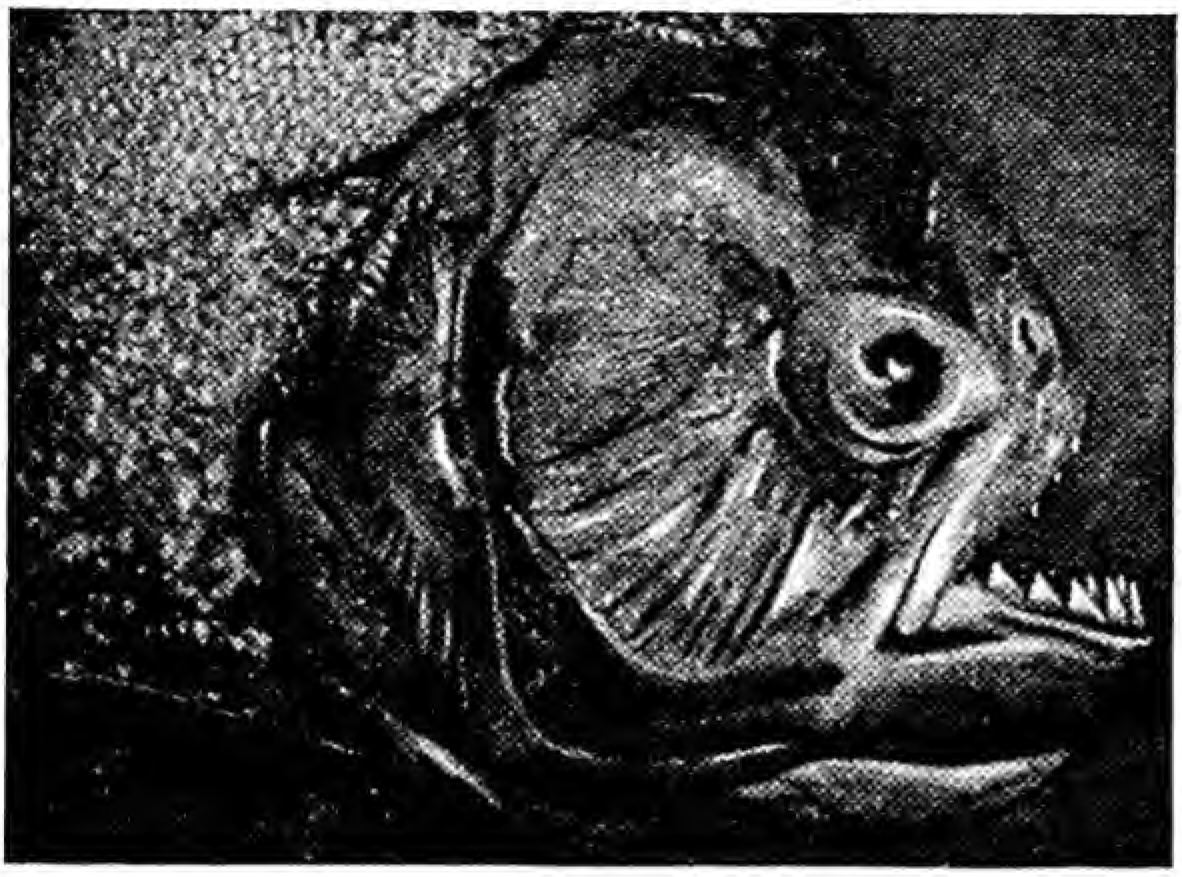
one side of the head, usually low down in line with the corners of the beak. Almost all birds are indeed wonderfully quick of hearing. Witness how knowingly they cock their heads, or hold them sideways, close to the ground. In all the owls these external ears are enormous, so that if one blows against the feathers of a dead or very tame owl, almost the half of one side of the head appears to be laid bare. Large as the ears are, they are trifling compared with those of the bats, or such creatures as the Maholi galago, aye-aye, and Cape jumping hare.

The bat's ears, combined with special sense organs often situated on the nose, have much to do with that amazing nicety of movement whereby a bat so seldom collides with any object, even when travelling at high speed. The ears apprize the bat of approaching obstacles by echo, much as ships use echoes nowadays whereby to take soundings, i.e. their distance from the sea floor. In some bats—and the Maholi galago—the external ears are so unwieldy that they have to be folded up when the animal retires to rest.

But the wonderful and picturesque ears of animals, and even the drum which lies well out of sight, are but a small part of the complex machinery necessary for hearing. In the innermost ear are minute structures lying in fluid. Within this fluid are also small particles of lime, and, according as these are floated from one side to the other, the animal apprizes its proper position in space. It is told how to keep its balance. Serious damage to this renders an animal unable even to keep on its feet.

Some very deaf persons, though normal in all other respects, cannot ride a bicycle. Variation on this theme of lime particles held in fluid—a simple form of spirit level, in fact—is found all the way down the animal scale. Even the jelly-fish carries on the margin of its disc minute sacs holding fluid and lime particles. Damage some of these sacs and the creature becomes immediately lopsided. Its sense of balance is gone.

Sound and touch, though to most of us sharply differentiated, are in reality only variants, different forms, of the same thing. A spider has no ears, but it shows itself as acutely conscious of a note given



FISH THAT SCENTS BLOOD
The piranha, or carib, is a small but ferocious and sharp-toothed fish found in Amazonian waters. It scents blood from afar off and will attack both man and beast. Its nostrils are clearly visible.

out by a tuning fork, as by a sudden twitch to one strand of its web. The fork sets up sound waves, and they strike the spider—if a small spider—with the force of a gale hitting a house. As a general rule, the more vocal or capable of sound production an animal is, the more likely is it to be furnished with an auditory apparatus.

Grasshoppers and crickets are notorious for their instrumental achievements. By rubbing wing covers and thighs together they fill the late summer air with music. But the heads of these insects, however carefully dissected, reveal no trace of an ear. On the thighs—or in some, what approximate to elbows—they carry minute drumheads, elaborate structures which catch the sound waves set up by other insects of the same species, and convey the message—which is usually one of love—to the brain.

Music of the Sea

Recent researches on *Crustacea* seem to point to the fact that lobsters carry on their legs special auditory hairs which, like aerials, collect sound waves. It is now known that the sea is full of sounds, and it may well be that there is yet a great deal to discover in the world of crustaceans usually regarded as silent animals. One quite common crustacean, the crawfish or rock lobster (*Palinurus*) so popular as a summer dish, is a case in point. By rubbing the base of each long feeler, or antenna, against the sides of its central beak, it can produce sounds very like the lowest notes of a base violin. They are clearly audible through many fathoms of water, and can be produced artificially in a dead specimen by making the long feelers simulate the movements carried out in life.

The ears of frogs, lizards and crocodiles can be clearly seen as flattened discs at the side of the head. Snakes, on the other hand, have no traces of external ears, although they are, to some extent, sensible to air vibrations. But the dreary gourd-flute music of so-called snake charmers, is not to be taken seriously. It is a piece of stage-craft used to impress the laity, nothing more.

Can Fishes Hear?

To what extent fishes can positively hear is still a very moot point. Within the heads of so-called bony fishes are two ear bones which serve to maintain the fish's balance, just like the lime particles in our own. In some fishes—such as big bream or haddock—these bones are as big as a finger-nail and much stronger.

The whole subject of animal acoustics is still a fruitful field of research, which has already yielded valuable results, findings which have been put to practical application in human aeronautics and submarine exploration. Many homely creatures, it is now realized, the mole and dog for example, can appreciate sounds of far too high or low a pitch to have any meaning for human ears. The scientist, Galton, invented a whistle which, emitting a note inaudible to a man, could still bring the man's dog running to heel.

Smell and taste are as closely related as sound and touch. Both taste and smell turn upon the impingement of minute particles,

from solids, liquids or gases upon certain special surfaces, called taste-buds. They may be at the back of the tongue or palate, so that whether the particles enter by the nose (smell) or mouth (taste) the result is virtually the same. To taste or smell fully, both mouth and nose must be in health. When our nasal passages are inflamed by a cold in the head, our food loses its savour. But if we hold our noses when in full health, by closing the nostrils with our fingers, taste is intensified.

The actual receiving stations for smell are, in ourselves, two small areas at the back of the nose, each about a quarter of an inch square. In the dog these patches, compressed into folds, cover an area at least fifty times this size. No wonder that a dog, companionable enough in the house, when out for a walk, is largely concerned with other matters. To his master, the world is, nasally speaking, largely a sealed volume.

It is somewhat depressing surely to reflect upon what man has done for the dog by domestication. Whereas the noses of bloodhounds, pointers, spaniels, etc., have been allowed to develop on natural and useful lines, those of the bulldog and borzoi have suffered usually at the dictates of senseless, show-bench fashion. The one has been compressed, the other elongated to grotesque extremes. The bulldog suffers from chronic bronchial disorders and the borzoi's nose is a useless appendage, for like all hounds of its particular group—greyhounds, Salukis, Afghans, etc., it hunts chiefly by sight.

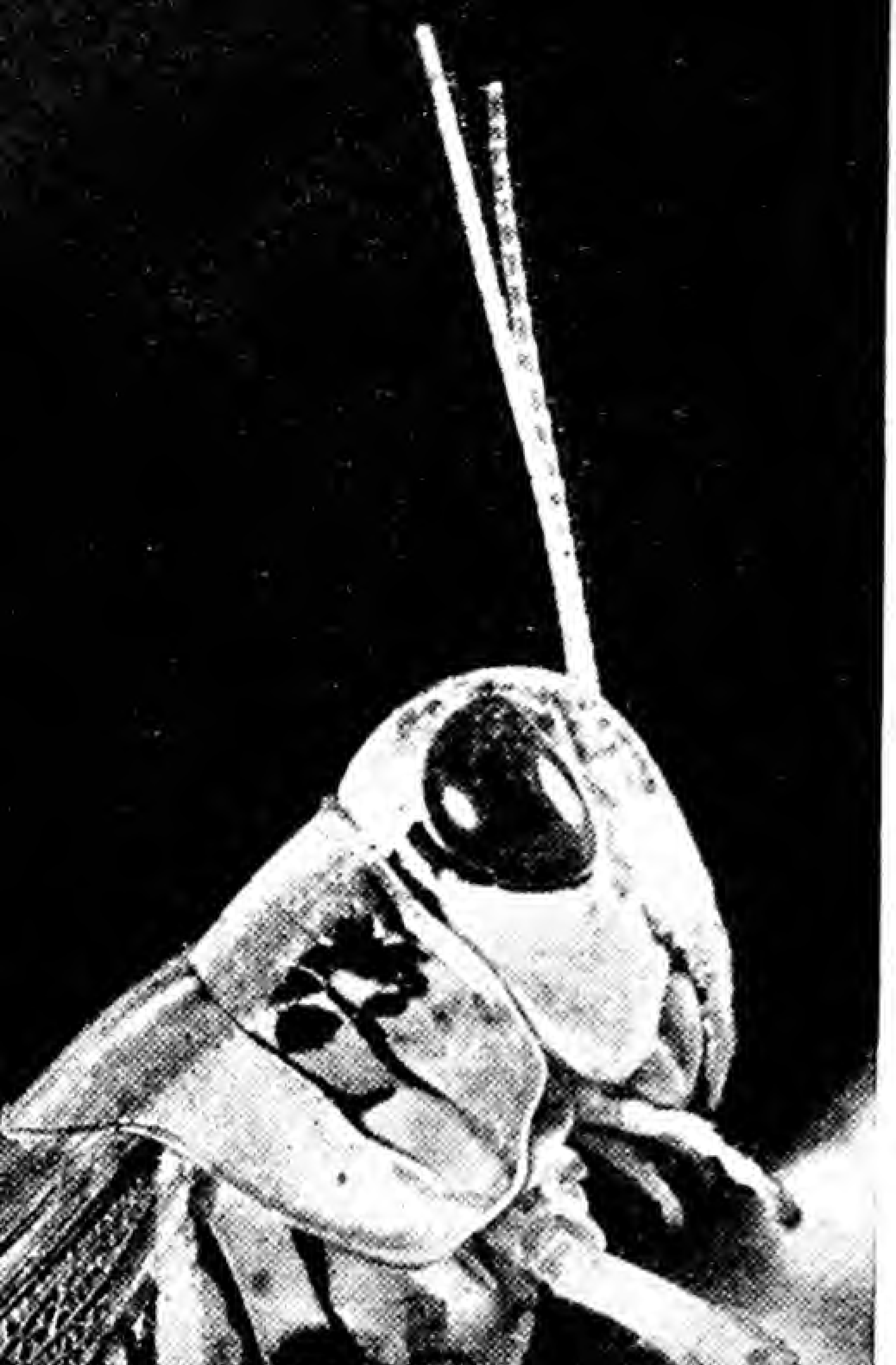
It is for psychologists to decide why the nose should be the accepted humorous feature of the body. The external olfactory organs of the mammals do certainly provide as bizarre a ring of changes on the accepted ideal of a nose as one could well desire. The majority of apes and most monkeys are as ill served with noses as ourselves. But the baboons, which live on open plains and rely for food largely by searching the sands for insects and small vertebrates—birds and lizards—have noses as well developed and as long as those of a wild boar or a stag.

Grazers' Sense of Smell

All plains-dwelling, grazing beasts have wonderfully sensitive noses, as every hunter knows. No smell, of friend or foe, travelling down wind escapes them. Some few, like the moose and saiga antelope of the steppes, have curiously drooping noses, the nostrils directed downwards. The same is seen in the giant panda of the western China mountains. It is believed this is a provision to keep out particles of wind-driven snow or dust that would otherwise obstruct the nasal passages. One or two aquatic beasts, the hippopotamus and crocodile, go to the

SMELLING FOR WORMS

The kiwi has nostrils at the end of the long, probe-like beak with which it locates worms in the ground. Digging is done with the powerful feet.



GRASSHOPPER'S ANTENNAE

Sense of touch in insects is located in the antennae, or feelers, long, pointed, delicate appendages carried in the front of the head. It is generally believed that the sense of smell often lies in the antennae.

opposite extreme and have the nostrils, like the eyes, directed upwards.

The limit in this regard is reached by the whales, which have the nostrils (blowholes) situated between the eyes, the outward orifice often several feet above the creature's brain-case. Only the sperm-whale bears them at the end of its snout. It is worth noting that whereas all other muscles of a whale are soft and lax, those controlling the blowhole are as hard as gutta-percha and yield only to a tenon-saw. This is a provision against any backwash of sea water when submerged, and consequent choking.

All animals that get their food from, or just below, the earth's surface have the nostrils placed at the end of the snout, and enormous olfactory bulbs at the forepart of the brain to receive the messages carried by the nose. Extreme cases are those of the ant-eaters and the elephant. In these animals the nose is unique in being converted into a digging tool or grasping organ. The elephantine trunk is unique in another regard. Just where the internal nostrils join the throat is a huge cavity as large as a football bladder. It is this, and not the trunk itself, which the elephant fills with water in order to give itself a shower (or dust) bath ; or possibly to drench someone it has cause to dislike.

Some few mammalian noses seem to serve no purpose save that of ornament. Cases in point are the proboscis and snub-nosed monkeys, the extraordinary inflatable noses of the elephant and bladder seals. The amazing nasal appendage of the star-nosed mole is like the elaborately sculptured noses of many bats, a super-sensitive organ of touch. Most birds have the nostrils near the eyes, but the kiwi, which lives on worms, carries the nostrils at the extreme tip of its long beak.

Nostrils are clearly discernible in many fishes and such fishes as the shark and deadly carib of Brazilian waters scent blood as quickly as the soaring vulture spies a carcase. One of the commonest shore fishes, the little bearded rockling, appears to have smell—or taste organs—in a groove on the centre of its back. The lateral line which runs along either side of a fish, it may be here mentioned, was at one time the subject of much speculation. It is a most complex system of tubes covered with mucus. At one time it was thought to have some connection with scenting food, but is now regarded as more nearly associated with hearing and the sense of touch.

How Insects Smell

In insects the same sense of smell would seem, as far as experiments have shown, to lie in the antennae, although in many moths these are regarded as serving more the purpose of aerials. It is interesting to note that a keen sense of smell is in many animals correlated with special scent-glands whereby members of a community

may keep in touch with one another. Amongst grazing animals, for example, powerful scent-glands are often situated between the toes and hoofs.

From nose to tongue is a short step. As we have seen, the back of the tongue may carry buds, but the bulk of the tongue performs a variety of other services. It is primarily a most useful organ of touch. The forked tongues of reptiles, for example, are used almost entirely as probes, to feel the ground ahead. One of the tree snakes is believed to use its tongue to fascinate its quarry, and hold its attention until within striking distance. In no reptile or other creature is the tongue a sting or organ of offence.

Our own tongues as well as playing their part in taste serve as a sort of hand, to roll our food into a bolus, and thrust it throatwards. Cats, rabbits, horses and many other mammals use the tongue as a washing glove. The lemurs carry this development further. A lemur's tongue carries beneath it an auxiliary tongue fringe which is employed to comb the animal's hair or to dislodge pips from between its teeth. The lion uses its tongue as a rasp; the ant-eater's tongue, heavily coated with adhesive mucus, is a living flypaper wherewith it licks up termites.

All creatures' tongues are attached to the base of the skull by a complex arrangement of bones, called the hyoid process. The ant-eater's tongue, however, is of such inordinate length and demands such powerful muscles to control it, that the hyoid process is attached not to the skull, but the summit of the breastbone.

Birds' tongues are often valuable organs of touch and may be fringed or covered with spines the better to probe tubular flowers, or help fish down the throat. The flamingo's tongue is enormous, and works on exactly the principle of an old-fashioned cabbage strainer. With it the bird forces out mud or water from its mouth, much as the whale does with its gigantic tongue, retaining only such matters as are edible. In birds which swallow their food whole, like the ostrich and pelican, the tongue is reduced to a minimum. In some fishes it may be altogether wanting. Most surprising of all tongues are those of the humming birds and woodpeckers. Both catch their food by shooting forth the tongue with terrific force. To obtain this force, the hyoid bones are fashioned like watch springs, coiling round the back of the head and finally being anchored firmly between the bird's eyes.

The chameleon's tongue may be shot forth to a distance exceeding the length of the animal. Like the ant-eater's, it is attached at its base to the breastbone. But the chameleon lacks the ant-eater's weight and moreover lives amongst slender tree branches. To save itself from being overbalanced at every outward thrust of the tongue, it holds on tightly with its prehensile tail to some stable object. The tail, in fact, serves like the recoil of a field gun.

It will be seen from the foregoing that feeling is a very relative matter. It depends first and last upon the size and complexity of the receiving station—in other words,

SCALY ANT-EATER
A pangolin, from the Belgian Congo. It feeds on termites which it licks up with its long, mucus-coated, worm-like tongue. It has no teeth.

the brain, which organ has attained its highest degree of development in the human being, although this may not always be apparent.

Plants and Environment

One of the most impressive features of the plant world is its infinite variety, not only in size and structure, but also in habit and distribution. All over the world, from the equator to the frozen lands of the Arctic and Antarctic; on the highest mountains; in humid tropical forests and swamps, or parched desert lands; in caves, in hot mineral springs; in ponds, lakes and streams; on the seashore and in the open oceans far from land, varied forms of plant life abound; a truly marvellous pageant of adaptive life.

Under natural conditions plants generally grow together in communities, the individuals of which not only mutually affect one another, but have come to accommodate themselves to all the particular circumstances of their surroundings. The physical conditions due to soil and climate and those produced by other plants and animals inhabiting the same region constitute what is termed the environment of that particular situation. The passage of the seasons, spring, summer, autumn and winter, also play their part; spring and summer witnessing the development and maturing in succession of a whole series of plants native to the same type of locality.

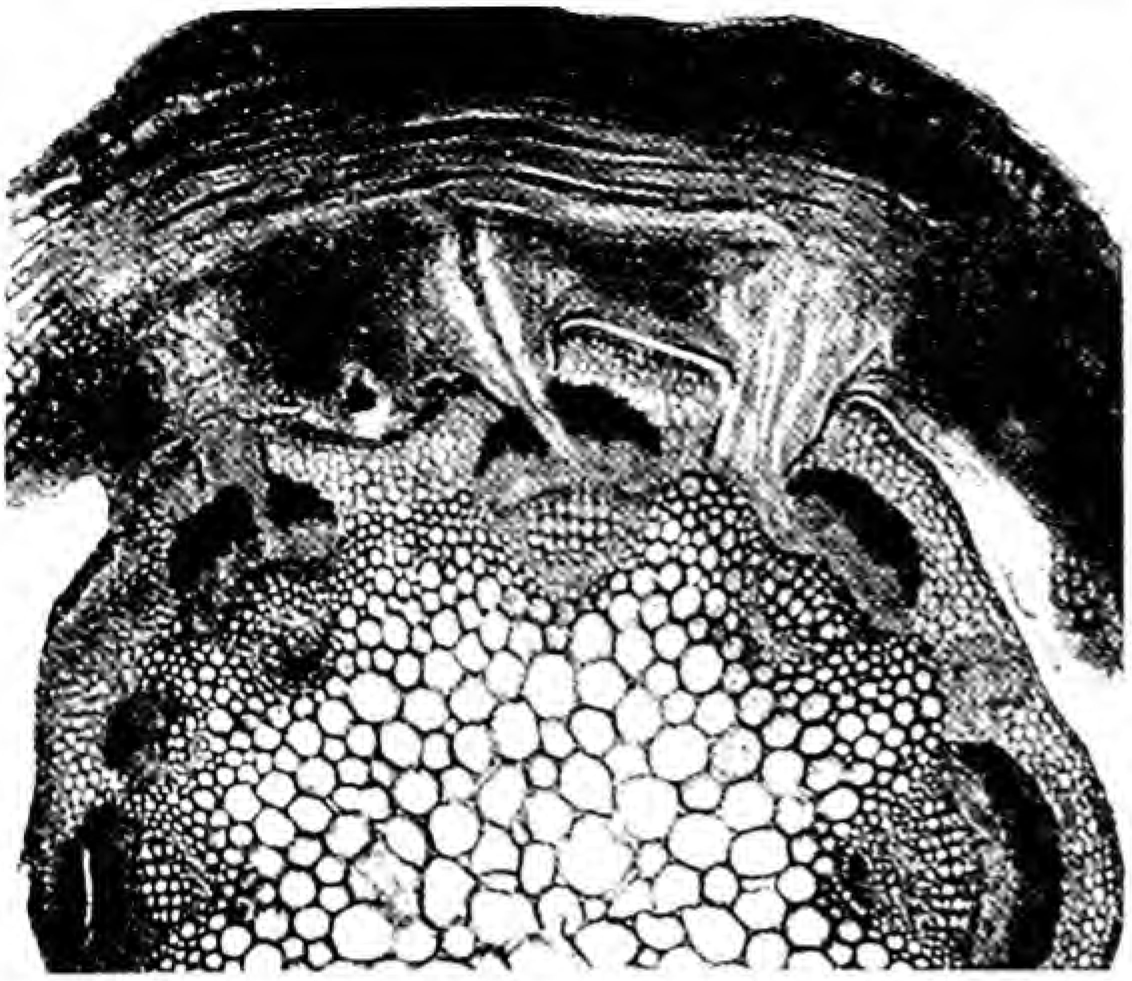
One of the commonest misconceptions regarding the plant world is that its members all lead a placid, static existence. Indeed, so universal is the error, that quite a false interpretation of certain words in common everyday use has become established, and unhappily perpetuated in some dictionaries, which give the definition of the word vegetable as "an organized body without sensation or voluntary motion." People talk about going away for a holiday and looking forward to *vegetating* for a few days. While the active-minded, hard worker proclaims that he or she, on retiring, has no intention of leading a *vegetable* existence; meaning actually, on the one hand, that they are looking forward to a period of rest and freedom from the petty worries of life, and on the other that they have no intention of leading an idle, aimless existence.

A more misleading definition of any living plant it would be difficult to conceive, as anyone who will take the trouble to devote a little time to watching the daily life of a plant growing in its natural environment, will soon realize. Growth alone entails movement, and as a plant increases in stature it moves from side to side in avoiding natural objects; while a whole host of unicellular aquatic plants perform very active movements throughout their lives.

Rest and Activity

Alternating periods of rest and activity constitute as integral a part of the life of a plant as of that of any animal. In early March the crocus opens wide its flower to a burst of early spring sunshine, and as quickly closes it when the sky becomes overcast with cloud. The tentacular, glandular hair on a sundew leaf responds and bends inwards to the touch of a tiny midge weighing less than the one-hundredth part of a grain. The wild hop and the bryony in the hedgerows wind themselves in ascending spirals round plants of more robust build as they climb to the top of the hedge in their search for sunlight and air. While underground, and therefore out of sight, the roots are steadily pushing their way through the soil, moving to right or left, over or under obstructing stones in their search for moisture and necessary mineral salts. How could anyone describe these as "organized bodies without sensation or voluntary motion"?

The seedling dodder sends its root into the soil, but only as a temporary anchor; for its lengthening shoot slowly, continuously, is moving in a circle, seeking to contact the stem of any nettle, wild hop, heather or other host plant growing in its vicinity. Once the host-stem has been found, the dodder attaches itself, by papillae which penetrate the stem of the host and give off numerous rootlets that coming into contact with the vascular tissues of the nettle or hop, absorb nutritive materials. After suitable attachment has thus been obtained, the dodder continues its twining growth with



FLOWERING PARASITE

The dodder grows as a parasite on heather and other plants. The photograph on the left shows a section of both parasite and host. Note how the dodder has sent down outgrowths from the side of its stem into the vascular tissues of its host plant. The dodder (below) has a long cord-like twining stem with pink flowers which grow in rosette-like bunches. It is without chlorophyll and the leaves are reduced to colourless scales.

increased vigour, and at the same time its base dies away, and connexion with the soil is severed. The dodder has literally moved away from its birthplace. Is that an "organized body without sensation or voluntary motion?"

Prime Necessities

Daylight, fresh air, elbow-room, above ground; a suitable soil yielding necessary moisture and mineral salts and other substances for absorption by its roots. These are the prime necessities of life for the plant. The soil may be said to be made up of a more or less loose collection of two kinds of material; mineral particles that have been formed by the breaking down or weathering of rocks, and organic particles consisting of the decaying remains of plants and animals forming collectively what is known as the humus of the soil. The particles of mineral material usually exceed the organic in amount, and their nature will depend upon the kind of rock from which they have been derived. Air and water fill the spaces between the particles.

The important characteristics of a soil, so far as the plant is concerned, are its capability to supply the necessary mineral salts, its air content, and ability to absorb and give up water. The organic humus of the soil is of importance to the plant owing to the valuable food-substances which it contains. Under natural conditions, plants and animals die and rot on the soil where they have passed their lives, with the result that much of what they have taken up from the soil is returned to it again in the form of humus and other products of decay. When land is brought under cultivation, however, this natural balance is upset, the greater part of the plant bodies forming the crop being removed, so that year by

year the soil becomes more impoverished, with the result that the farmer has to provide frequent applications of manures, if he is to keep his land in good heart, as it is termed, and by this means replenish the stocks of food-substances required by the plants for healthy, vigorous growth. On the character of the soil, that is to say its mineral content, humus and depth, will depend the type of plants that we may expect to find growing in any given situation.

Thus, on the South Downs of Sussex, where only a few inches of soil rests upon the basic chalk, we find a flora consisting primarily of dwarf herbs and short turf, while the rich loam lands of the Weald, spreading away inland from the foot of the Downs, support a luxuriant and most varied plant population, including magnificent deep-rooted oak, beech and elm trees. On the seaward side of the Downs, on the other hand, the belt of loam gradually merges into the salt marshes and shoreward sand dunes, each having its own typical plant population.

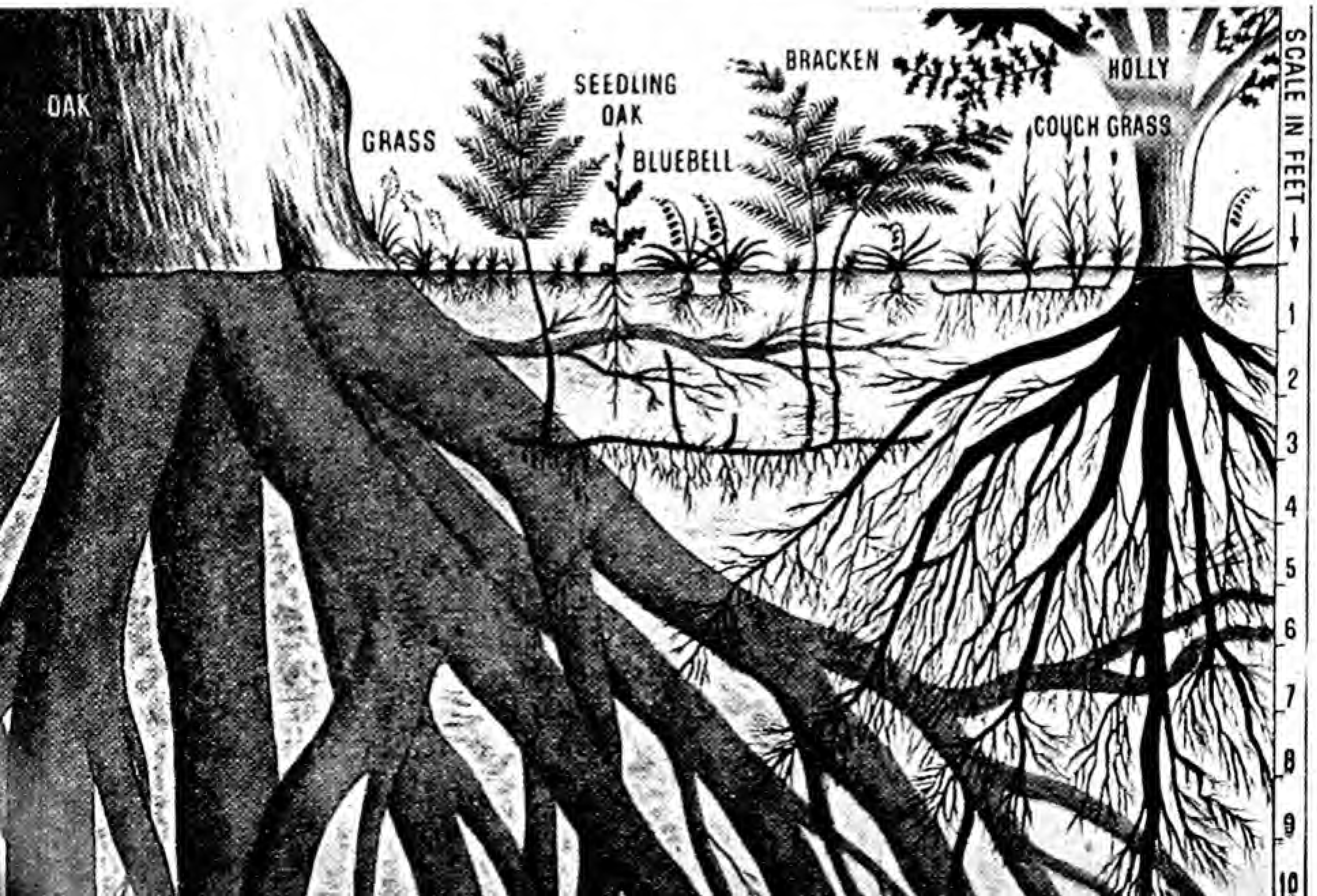
This presence of characteristic plants in any particular situation is evidence that there they derive some benefit gained directly or indirectly from the nature of the soil or from the absence of plants that under different conditions might well prove successful competitors in the occupation of the ground. However, matters are not always quite so simple as that, for whilst every habitat may be said to confer a marked benefit upon its legitimate inhabitants, adaptations to its special conditions are also involved, and particularly to those conditions which are most pronounced.

Why Certain Plants Predominate

Therefore, we shall find in any locality that it is the particular factor which most nearly approaches the minimum requisite for life, or which is present in excess, be it light, food-supply, or water, that will always be the one most profoundly affecting the character of the vegetation. Should the other essential conditions be amply sufficient for the minority, if not all the species present, the successful plants will be those best able to flourish and complete their life-cycle under the particular defi-

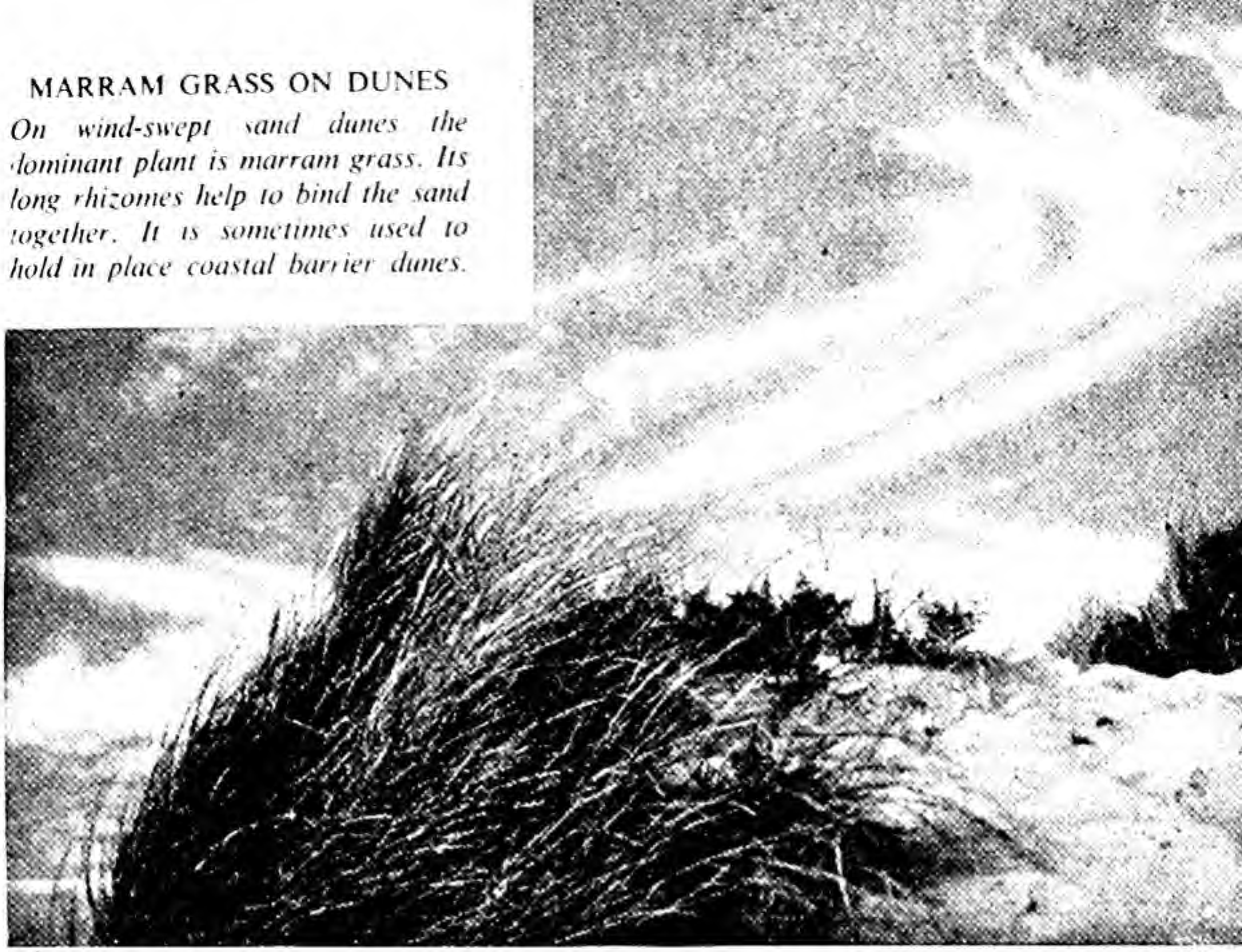
PLANT COMMUNITY IN AN OAK WOOD

Section of soil showing how grasses, bracken and bluebells live together in a dry oak wood, their roots being at different levels. Holly is the commonest shrub in this type of wood



MARRAM GRASS ON DUNES

On wind-swept sand dunes the dominant plant is marram grass. Its long rhizomes help to bind the sand together. It is sometimes used to hold in place coastal barrier dunes.



ciency or excess; and they will form the dominant plants of that region.

A strip of woodland composed of oak, ash, maple, birch and holly, more or less typical of England's southern counties, is an ideal situation in which to observe many examples of adaptation and seasonal development, for it represents a plant community which may be said to be composed of three tiers, namely the trees, the undergrowth consisting of hazel, hawthorn, sloe and brambles, and the ground flora or carpet of herbaceous plants. Water, light and air, these are the vital factors in the life of all green plants, and it is in their endeavour to obtain adequate supplies that their remarkable and varied form and habit, which fit them to the particular situation in which they live, have been developed.

If we visit such a strip of woodland in early spring, the trees still lift their naked branches to the sky. Everywhere there is a flood of light and air, and already the male catkins of the hazel hang down in pale golden-green tassels, for their work must be accomplished before the hazel leaves unfurl. From the middle of February onwards, plant-life on the floor of the wood is awakening from its winter sleep and the firstlings of the year begin to make rapid growth.

For the most part they are plants of low stature, many of them only two or three inches in height, easily to be overshadowed by taller and more robust types. Therefore, if they are to survive and perpetuate their species, they must have expanded their leaves, opened their flowers and fertilized their ovules, before the plants of stouter growth have had time to expand and deprive them of the maximum light and air.

To meet and overcome these dangers, they have become adapted to carry out the most vital part of their life-cycle during the first weeks of spring. The dog's mercury (*Mercurialis perennis*) is one of the earliest, its small, inconspicuous, green flowers, like those of the hazel, depending upon the wind for fertilization. About the same time, the golden, star-like flowers of the lesser celandine (*Ranunculus ficaria*) expand and are visited on sunny mornings by certain dipterous flies and early bees. These are followed by violets and wood anemone (*Anemone nemorosa*), and soon the floor of the wood is carpeted with sheets of pale yellow, fragrant primroses, with here and

SPRING-FLOWERING PLANTS

Crocuses are among the earliest of the spring flowers; they grow from corms and flourish best in short grass. The primrose also flowers early before it is overshadowed by the taller and robuster plants which share its woodland home.

LADY'S SMOCK

Also known as cuckoo flower because it arrives with the cuckoo. It thrives in moist meadows or in swampy ground.

there a clump of waving, palest-pink flowers of the lady's smock (*Cardamine pratensis*), and the small, white flowers of various early crucifers. Last of the striking spring flowers, towards the end of April, vistas of exquisite blue of the wild hyacinth or bluebell (*Endymion nonscriptum*).

By mid-May almost all have finished flowering and set their seed; the leaves of the trees have expanded and form a canopy of pale green through which the sun filters down in shafts of golden light. A new series of herbaceous plants of stouter growth lift their leaves, fretted and cleft in shape, into the air and light, all better adapted to the changed environment of partial shade and sunlight.

Contrast in Beech Wood

In marked contrast are the conditions to be found in a wood composed entirely or chiefly of beech trees, such as we find on the chalky soils in south-east England, at the foot of the North Downs, for example, where from May to October uniform shade prevails. One is at once struck by the paucity of the ground flora, although wherever a clearing occurs or the trees are sparsely scattered it becomes abundant, showing obviously that it is not the soil which is at fault. The beech casts a far deeper shade than oak or ash, owing to its extensive branching and consequent perfect leaf mosaic, while on account of the slow rotting of its leaves, there is often not much humus available in such a wood. Dog's mercury is one of the most dominant of the ground flora, obviously because it flowers long before the beech leaves have expanded, and other early flowering plants are to be found in the better-lighted parts of the wood, including as the season advances, sanicle (*Sanicula europaea*), enchanter's nightshade (*Circea lutetiana*), and some species of orchids, while there is a marked absence of bushy undergrowth.

On open common-land with a non-calcareous soil, the dominant plants are usually those possessing an armature of spines and prickles, an adaptation of stem, branch and foliage against the onslaught of herbivorous animals. In such a situation, areas of short turf and coarse grasses alternating with thistles, hawthorn and masses of gorse, blackberry and wild rose, constitute the prevailing flora, associated with many low-growing herbaceous plants, such as speedwell, pimpernel, etc.

An old country lane offers a complete contrast in environment and an entirely different flora. Honeysuckle, bryony, con-

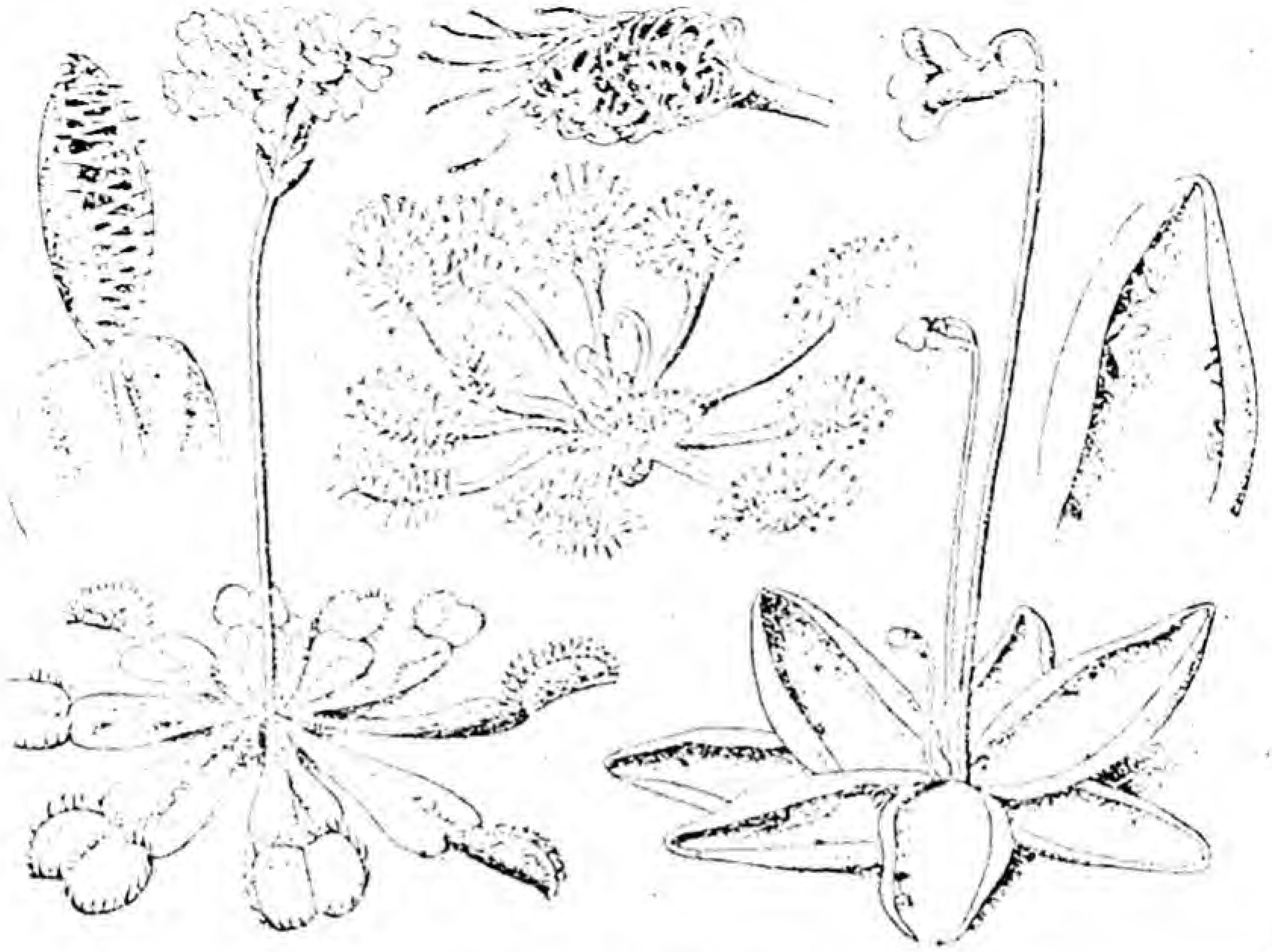
SPREADING BOUGHS IN A BEECH WOOD

Ground flora in a beech wood is never luxuriant, as little sun can penetrate through the spreading, leafy boughs. The leaves rot slowly and the soil is poor in humus.

volvulus, and the wild clematis or traveller's joy (*Clematis vitalba*), climb freely over the hawthorn, blackthorn and sloe of the bounding hedges; while the banks are clothed with an amazing assortment of herbaceous plants, showing a wonderful variety of leaf-form, so shaped and adapted to the crowded situation, that each shall obtain the maximum possible amount of light and air.

On wide stretches of moorland the sandy soil is usually poor or deficient in certain mineral salts, often acid, and relatively lacking in humus. Here the dominant plants are members of the heath family, the common heather or ling (*Calluna vulgaris*), and the Scotch and cross-leaved heaths (*Erica cinerea* and *E. tetralix*) much-branched shrubs, usually of low stature with tough, wiry stems and small, entire leaves, associated with colonies of bilberry (*Vaccinium myrtillus*), cowberry and cranberry (*Vaccinium vitis-idaea* and *V. oxycoccus*), also of shrubby growth, with here and there clumps of Scotch pine and bracken. On the moorland bogs, in addition to heather, we shall find a luxuriant growth of bog or sphagnum moss from the remains of which the great beds of peat are chiefly formed, and in such situations two of our most interesting so-called insectivorous plants, the sundew (*Drosera*), and the butterwort (*Pinguicula vulgaris*), are found.

Both these plants are striking examples of adaptation to a special environment, obtaining their supplies of nitrogen, in which the surrounding soil is deficient, by the capture of insects. For this purpose the leaves of both plants have become specially adapted. In the sundew, the leaves are covered with stalked, glandular hairs or tentacles, each hair terminating in a knob-shaped gland which secretes a sticky fluid. Any insect alighting on the leaf, or touching one or more of the glandular hairs, is at once entangled and held by the gummy secretion, its struggles to escape only serving to bring it into contact with more of the hairs. Those on the outer edge of the leaf being longer bend inwards in response, while the centre of the leaf becomes slightly concave, and in this depression the insect is soon partly hidden from view by the reflexed hairs, which stimulated by its presence pour forth a copious secretion which ultimately dissolves the soluble parts



INSECTIVOROUS PLANTS

Trapping mechanisms of three insect-eating plants. On the left is Venus's fly trap; the small drawing shows the trap closed. Sundew (centre) grasps its victim with sticky, glandular hairs. The leaves of butterwort (right) fold inwards over the captured insect.

of the insect, and renders them available for absorption by the glands of the leaf.

In the butterwort, the glandular hairs are not so large but function in the same way, and the blade of the leaf folds inward and over the captured prey. Both plants grow very loosely rooted in the surrounding mossy bog, and their leaves have definite selective powers, showing no response to gusts of wind or particles of wind-blown sand, but their glandular hairs become active and responsive to the lightest touch of the smallest midge.

On the high, waterless plains of Mexico we find in its highest development another type of specialized adaptation, a type of flora which has become adapted to life

HOUSE LEEK (SEMPERVIVUM)

This little evergreen plant grows in dry, rocky places. It stores up reserves of water in its succulent leaves and stem.

IN A BRAZILIAN FOREST

The warm humid atmosphere promotes rapid growth and life on the part of many of the plants is a struggle to reach the light. Note the luxuriant undergrowth.

under desert and arid climatic conditions. In these so-called cactiform plants the green tissue is situated in the cortex of the stem, and the epidermis covering it contains stomata just like the epidermis of the leaves, and functions on the whole in the same manner. In those species that are richly branched and in which the branches are short, they frequently resemble thick-leaved plants. Frequently, the separate portions of stem and branch take on the form of fleshy leaf-like disks as in the well-known prickly-pear (*Opuntia*).

To the cactiform plants belong also the leafless candelabra-like, tree-shaped spurges of Africa and the East Indies. The whole organization of these plants is adapted to their environment of dry, sandy, stony plains and waste rocky plateaux almost completely wanting in soil, where no rain falls for about three-fourths of the year; usually, in fact, the driest parts of the earth. In these plants dry scales and hairs are developed instead of foliage-leaves, or these are often metamorphosed into fearsome thorns which project in great numbers from the thick stem-structures, and most effectively protect them from the attacks of thirsty animals ; while in their stem tissues peculiar aggregates of cells have become adapted for the storage of water.

Plant Life in Tropical Forests

From the arid, sun-scorched plains of Mexico where the conservation of water is the vital factor, we turn for our last illustration of the extraordinary adaptations of plant-life to the humid forests of tropical South America, perhaps the greatest contrast in environment one could imagine, an environment where the struggle for existence reaches supreme intensity. There a perpetual green twilight reigns throughout the hours of daylight, and the hot, still air is supercharged with moisture.

To rise out of this perpetual twilight of

the forest depths, and if possible reach the open daylight, is the major problem and condition of success. And so we find first immensely tall, straight-stemmed trees, then twiners and climbers which strangle and overshadow these, while strange epiphytes and parasites perched aloft grow and scatter their seed over the tangled roof, the whole forming a dense, leafy canopy arching over the gigantic stems of the primeval forest, lit by stray sunbeams. On the floor, ferns and mosses and other shade-dwelling plants abound among the confused and tangled masses of roots that render further progress almost impossible.

Everything climbs, winds and twines with everything else in the struggle to reach that green roof and beyond. Where the climbers have grown old with the trees on which they cling, and the older portions of their stems have become denuded of foliage, they resemble thick ropes, slowly strangling the life out of their support. Species of *Clusia* growing up from the ground wind a strangling network of stems around some lofty monarch of the forest, slowly compressing and strangling it, but ever growing upwards until at last they reach the sun in ultimate triumph.

Strange aroids perched on the branches of the trees send down long cord-like, aerial roots into the soil; while many gorgeous-flowered orchids lead an epiphytic existence, attached to the bark on the upper surface of the branches, sending forth a fringe of aerial roots to absorb water from the vapour-charged atmosphere. All alike have become adapted in structure and habit to their forest environment, winners in the struggle for existence in a difficult world.

Test Yourself

1. In what different ways have octopuses and mussels adapted themselves to their environments? Why is the ability to move rapidly more important for an octopus than for a mussel?
2. How is the body of a bird adapted for life in the air? Do other animals (apart from insects) fly? Name a few.
3. Which do you consider the most primitive of all the five senses?
4. Name some different ways in which animals carry their eyes. Why do the grazing animals have theirs set more laterally than man's?
5. How is balance associated with hearing in some animals?
6. Mention some different uses of the tongue in animals. What are taste-buds?
7. What are the prime necessities of life required by a plant to sustain it in vigorous growth?
8. Why are certain species of plants peculiar to certain situations? Give examples.
9. Why are certain plants typical of spring, and others of summer?
10. What special modification of form and function have plants living in very dry hot regions undergone to help them to conserve and store water?
11. What are the chief problems in life among plants living in dense tropical forests?

Answers will be found at the end of the book.

POLECAT IN ITS TREE-TRUNK LAIR

This innocent-looking little face quite belies its owner's true character. Like all members of the weasel family, the polecat is extremely vicious and appears to have a lust for killing, often destroying more than it can eat and storing the remainder.

CHAPTER VII

HOW ANIMALS BEHAVE

THE scientific study of animal behaviour is a comparatively recent cult. Research has been carried out by two principal schools of thought, one in Russia under the leadership of Professor Pavlov, and the other in America headed by Dr. J. B. Watson, the Russians working chiefly on dogs, whereas the American school has confined its research largely to the man-like apes and the human child.

Undoubtedly, the results achieved have been of tremendous value, particularly in the field of human psychology, but this subject belongs more properly to Chapter IX, which deals with intellectual man.

Behaviour is the way in which living things respond (or react) to their environments. All living things have the ability to react in one way or another to certain influences, or stimuli, and this particular quality—sensitiveness—is one of the most important differences between living and non-living things.

Among the chief stimuli to which living things respond are touch (or contact), temperature (coldness and heat), sound, light, smell, electricity, and so on. The reaction of an animal to a stimulus depends upon the extent to which its senses are developed.

Thus, in amoeba and other one-celled animals, which have no special sense organs, the reactions are limited to certain stimuli, such as heat and light and the proximity of food. Some creatures are sensitive to chemical changes. A slipper animalcule, for instance, will move away from strong light or very salty water (which it dislikes) but will swim into a drop of weak acid and remain there.

The nature of the reaction to the same stimulus will vary with different animals. An earthworm, for example, will not respond to the stimulus of sound, because it has no organs of hearing.

As a general rule, the senses become more acute as the scale of life ascends, although in some cases one sense may be more strongly developed while others are lacking. A dog, for example, has a much keener sense of smell than man, and a bird has sharper vision, but both are inferior to man in brain power.

In man and the higher animals, the chief sense organs are connected to the brain by the nerves and it is the nervous system which controls the behaviour of the whole body, whether it be automatic, involuntary (instinctive) or voluntary.

The simplest kind of reaction is called a tropism, meaning a turning movement.

Rather more complex reactions are known as reflexes and when these are quite involuntary, such as dropping a red-hot coal, they are called simple, or unconditioned reflexes. Reflexes which are the result of something learnt from experience are called conditioned reflexes.

The urge which causes an animal to perform the things necessary for its everyday life is known as instinct. Instinct is an inherited quality and as a rule the smaller an animal's brain the more it acts by instinct. The larger-brained animals are also activated by instinct but they possess the ability to learn new things and can find ways out of difficulties—they are able to improvise.

Instinct or Reasoning

Instinct may take many forms, some quite simple, others more complex, but all provide interesting study. Sometimes the most lowly animal may alter its instinctive action by what appears to be intelligent behaviour and it is difficult to differentiate with exactitude between instinct and intelligence.

It is, in fact, unwise to say that wild creatures *do* this or do *not* do this, that or the other. Circumstances adjust their behaviour, and what is true here may not be true there, what is true one season may not be true the next. At the same time, it is

unwise to disbelieve anything fairly reasonable concerning them. It is surprising what strange things eventually prove to be true, and every year one's outlook on so vast a subject is apt to undergo a certain amount of adjustment and expansion.

Ferocity

Among the vertebrates, some of the most ferocious belong to the waters. One need look little further than the pike of British lakes and rivers for that soulless and brainless ferocity which characterizes so many of the creatures of the deep, but one must not conclude that all fishes are incapable of affection and those other higher senses by which man stands supreme. Some of them, indeed, are excellent wives and husbands, and as is well known to anyone who has kept an aquarium, quite a few are capable of some kind of affection even for human beings.

Turning to the warm-blooded quadrupeds, probably the most ferocious are to be found among the larger weasels, such as the fisher and the wolverine, while the Tasmanian devil is in a class by himself. But the weasels are so highly gifted and so perfectly equipped as demons of murder that as a class they stand alone. The fisher, for example, is little larger than the otter, yet he will follow a fox for many miles, and finally run it down and destroy it. The northern lynx, with its terrible claws and fangs, is a tough type of adversary, and has been known to kill a Red Indian armed with a knife, but if the fisher, half his weight, sets out after him, his fate is probably sealed. The fisher runs his quarry by scent, as the common weasel and stoat do, and why he is so named does not seem to be known, as one of the few things he probably does *not* do is to fish.

Another curious thing about this most ferocious of the immense weasel family is that he seems almost impervious to wounds. Often the pelts of these beasts, healthy and full of fight when trapped, are

DEADLY TASMANIAN DEVIL

As its name implies, this comparatively small animal is one of the most ferocious and most feared. It prowls by night and is a menace to sheep yards and poultry runs.

PORCUPINE'S SPIKY ARMOURY

Porcupines have been provided by nature with weapons for warding off attacks by other animals. When attack is threatened, it erects its quills. There are several species of porcupine found in different parts of the world. Above is one from the eastern hemisphere.

found to be so perforated with scars as to be utterly useless.

One of the most dangerous animals in the Canadian forests for any other animal to tackle is the porcupine, for as is well known the point of each quill is covered with barbs, which stand up as they enter the victim's warm flesh. Thus, not only is it next to impossible to remove the quills, but they gradually work inwards, till eventually they reach some vital organ, having caused a lingering death. It is said that when the stern alternatives are porcupine or starvation, the lynx and the bear will occasionally place a cautious paw under the porcupine's stomach and hurl him against a tree trunk, dismembering him at their leisure, but generally speaking most predatory animals prefer to leave the porcupine alone.

Not so the fisher. He goes straight in and kills him as a staple entry on the menu, and in porcupine country nearly every fisher taken is found to be full of quills. But they rarely, if ever, do him any harm at all. The quills collect and work flat under the skin, and gradually travel along the back to the roots of the tail, where they eventually work out.

Next to the fisher, the wolverine might be taken as an outstanding example of ferocity, in that he will unhesitatingly attack and generally kill many creatures larger than himself. The wolverine is known also by the names of glutton, on account of his gluttonous habits, and skunk bear, because, next to the skunk, he is supremely equipped with musk glands. Practically all fur-bearers possess these glands in a greater or a lesser degree of development. The glands are situated in the rectum, and with such beasts as the beaver they function mainly in assisting the sexes to find each other. They provide the scent which fox-hounds follow and it is a curious provision of nature that the more afraid or excited or overheated an animal becomes, the more the glands discharge and the stronger the scent.

Musk glands are very highly developed

in nearly all the weasels, excepting the pine and beech martens (hence the name sweetmart as distinct from foumart—foul marten—applied to the polecat) but they reach their zenith of development in the skunk, closely followed by the skunk bear, or wolverine. In their cases the evil-smelling, stifling fluid can actually be ejected, and heaven help anyone who gets the merest spot of it on his clothing.

The wolverines generally follow the wolf packs, and live largely by robbing them. If the wolves kill a deer in dense timber, the wolverine, climbing from tree to tree, musks the kill from overhead; if the wolves make their kill in the open, as is more general when the winter packs are assembled, the wolverine awaits his chance, then makes sure that the wolves will not return for a second feed. Wolves generally kill far more than they can eat—one may find seven deer lying together untouched—so that the wolverine fares pretty well in wolf-infested forests. And no fool can rob a wolf!

If a dog is offered a piece of meat which a wolverine has musked, the reaction is instantaneous. Having sniffed it, he grimaces and rolls in the snow, bristling from end to end and displaying every evidence of nausea. The wolverine is also a notorious cache robber, and has cost the lives of many good men—particularly Indians. The Indians of the barren lands of Ungava

KING OF THE JUNGLE

The lion is less fierce than is generally supposed. By nature it is somewhat indolent but its immense strength gives it superiority over other animals.

STOAT SNIFFS THE AIR

Another member of the weasel family, the stoat, is a vicious little beast with a long, snaky body. It preys on rabbits, hares, birds and smaller creatures and tracks its victims by scent. Rabbits when chased by a stoat often become paralysed with fear.

and Labrador, for example, follow the immense herds of caribou, killing as they travel, and storing the meat in pits, covered with boulders, for the return journey, which will take them back to their fishing and wildfowl grounds as spring approaches. If a wolverine strikes the line of caches, he will musk cache after cache, so that the Indians find themselves foodless in dead of winter. So great is the strength of the wolverine that nothing will keep him out, not even a foot of ice, and, owing to his activities, whole tribes of Indians and many a good prospector or explorer have perished of starvation.

Degrees of Ferocity

Owing to the superb strength of such animals as the lion and the tiger, we are apt to regard them as pretty well top of the scale in ferocity, but the cats as a family are gentler than the weasels. The lion is more dog-like than the tiger, and the leopard is more weasel-like and treacherous than either of them. It is fortunate that we have no true weasels the size of the tiger (or weasels that can fly), for they are the most gifted and active family on earth. Nearly all the bears are treacherous and undependable, and it is not generally realized that the sleepy sloth bear kills more people in India than tiger and leopard put together—more than any other creature on earth, probably, excepting the serpents.

One can hardly classify the denizens of the seas from the point of view of ferocity, so much depends upon their size, which governs their ability to kill, and on their mode of life. One of the most dangerous is undoubtedly the killer whale, owing to its unpleasant habit of attacking—even a fairly large vessel—unprovoked. Divers maintain that the most dangerous fish in the seas is the outsize cod, which attains a length of eighteen feet or over, and for his size has the biggest mouth and the highest gift of swallowing of any creature known to man.

Packing

So far as animals are concerned, we usually regard the habit of packing as most intimately associated with the wolves, but they are by no means alone in this respect. Animals pack in order to obtain better results from their hunting, and packing must not be confused with the immense armies of certain species, which foregather together in times of migration.

True packing does, of course, occur with the wolves, and is common to most of the dog tribe—coyotes, hyenas, Cape hunting dogs, jackals and so on. Even some of the cats form themselves into loose, badly organized packs in times of extreme scarcity, and when a pack of lynxes sets to work to drive the snowshoe rabbits out of

CAPE HUNTING DOG

Most members of the dog tribe hunt in packs and African wild dogs are no exception. Their chief prey is antelopes but large packs have been known to attack man.

the ice-encircled islands, the night generally becomes hideous.

A pack may consist of a family—parents and cubs of the season—hunting together, or of several families united. With the Canadian timber wolves, for example, a pack seldom outnumbers seven, parents and cubs, but the wolves of Northern Europe gather into immense packs. The European wolf has few of the noble characteristics of the timber wolf of Canada, but occasionally—in Alaska at any rate—an exceptional winter may cause several families of timber wolves to unite. It is generally found, however, that these large packs are on the move, and are migrating first and hunting as they go.

In Great Britain, stoats afford about the only example of true pack-hunting, and many keepers have stories to tell about encountering summer packs of stoats. In this case, packing is most noticeable in mountainous country, and the following is probably the explanation. At the time when the hill birds, such as grouse, ptarmigan, curlews and plovers, are nesting, the stoats drift into the high country, and for a month or so have a wonderful time among chicks, eggs and old birds. But this harvest comes to an abrupt end, and there is nothing for it but for the stoats to get out and get down to rabbit country.

Animal Migration

We now come to packing of quite a different kind, not for purposes of hunting, as the predatory animals pack, but the urge of vast armies, drawn by a single purpose, their common aim bringing the many small parties together till they become a multitude. Thus, they find security and comfort in numbers, but their migrations—prompted by food supplies—may be beset by danger.

Perhaps the most outstanding example of migrating millions was afforded by the American buffalo, which once packed the plains of that continent in incredible numbers. As spring came to the valleys of the Mississippi, the Missouri, the Red River and away west into the Rockies, the buffalo families began to stream over the ridges, each clan led by a great-grandmother of the herds, each buffalo grunting as it trudged. They were slow-thinking, slow-moving beasts, but with the migration fever upon them there was no dallying, no turning back, and so army joined army until immense gatherings were formed—an area 400 miles in width and 200 miles in depth, packed black with buffaloes. And behind them came the ghostly runners-up and undertakers—from the timber wolf to the giant grizzly.

When the Ice Cracked

The ice of the great rivers was still intact, but rotting steadily from below, and imagine what happened when these millions of tons of beef began to cross! The vanguard crashed through, then rank after rank, tier upon tier, their followers were trampled and crowded to their doom by the unseeing mass behind. So old travellers told how for many weeks each spring the banks of these water-ways were unapproachable owing to the stench of the thousands of stranded hulks, and it is a fact that settlements stand today on islands originally built up from the carcases of stranded buffaloes.

But they left behind them a lasting relic, for the buffaloes knew the best and the easiest roads, and today the great trans-continental railways thunder through the mountains by the exact roads originally trodden black by multitudinous cloven hoofs.

Thus, as the buffaloes travelled before the white men exterminated them, the caribou travel today through the wastes of the North. Time has specially equipped them for these great journeys—hence the spreading hoofs which prevent their sinking in the snows, which help them to propel themselves when swimming the lakes and rivers, and which click at every step. This serves the same purpose as the twittering of small birds on migration—it tells each beast where his neighbours are in storm and darkness. Another outcome of evolution is that every hair on a caribou's body is in reality a hollow quill, so that he floats high out of the water, buoyed up by his coat, and a swim of twenty-five miles is nothing to a caribou.

From the elephant to the seals, shrews,

lemmings, including rats, mountain hares and many of the antelope family, many classes of animals mass for migration, and even the homely old hippo gets the travel fever at times. If over hunted in their home locality or if food becomes scarce, the hippo move downstream, in the old days in considerable herds, and swim surprising distances out to sea, until instinct or tradition takes them to the mouth of another river, offering better living conditions. Migration is a never-ending subject, which the student must study for himself.

Hibernation

While most of the reptiles and many of the fishes, such as tench, carp and eels, hibernate in the true sense, this habit of sleeping away the winter seems to be more or less a matter of convenience in the case of most warm-blooded animals. If, for example, you take a bear from Arctic regions and give him food and warmth, he probably will not den up for the winter, and though he may have his sleepy periods, he will remain active while his wild brethren are deep beneath the snows.

Normally, bears in the cold countries *do* hibernate in the true sense. They hide away in some sheltered place, and in due course the drifts pile over them. Their breath seals the inside of the chamber with ice, so that in some cases they could not escape, even if they wanted to, until the thaws of spring weaken the crust. During this period respiration almost ceases, the digestive organs become inoperative, and the heartbeats sink to a flicker. The den is always marked by its airshaft, and hibernating bears can be dug out and taken captive without difficulty.

When a bear wakens from his hibernation he is then, if ever, dangerous to man. His first effort is to stagger down to water, and dazed and weak with hunger he is apt to hit out at anything which comes within his reach. One of the worst bear tragedies on record occurred on the Etomami River. One Sunday afternoon, two lumbermen were walking by the river when they saw a large black bear (presumably) rooting about along the margin. These men were quite used to bears in the summer—as many as forty may be seen in a day's travelling—and normally one takes no more notice of them than one would take of so many jack rabbits.

The men did not count on this bear being newly awakened, so they shouted at him, expecting him to scuttle, instead of which he made straight at them. One of the men was knocked down and killed instantly, the bear breaking his neck and tearing away his right shoulder. This gave the other man the chance of a lead, but strangely enough the bear followed him. Despite the man's heavy rubber boots he managed to reach camp, and ran into one of the bunkhouses, shouting the alarm and slamming the door behind him.

The cook in the cookhouse saw what was happening, and ran into the compound, armed with a small automatic pistol, just as the bear entered it. From all reports he fired shot after shot in such quick succession that the noise of the little weapon was one continuous roar, but the pistol was of too small a calibre to have any immediate effect. The bear reared up and killed him too, then, dripping blood, it left the place.

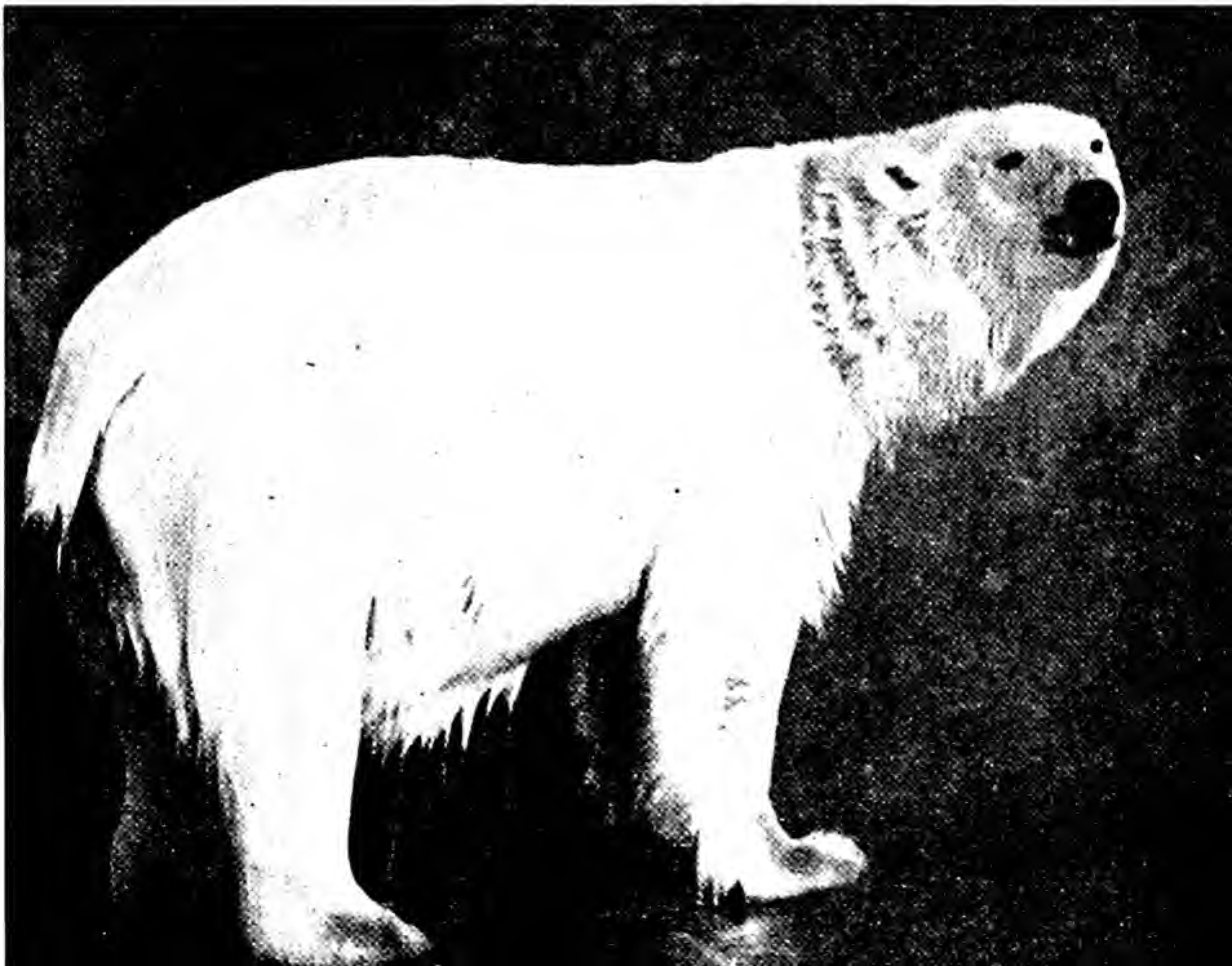
At the subsequent inquiry it was said that a Cree Indian had taken up the blood trail of the bear, but came to the conclusion from its tracks that it was not a black bear, but a grizzly. Therefore, he wisely gave up the hunt, and the bear probably crept away and died of its pistol wounds. But it is hard to believe that it really was a grizzly ; one might as well talk of a Scottish wild cat in Cumberland as a grizzly, those days, so far east. In all probability it was a very large male black bear, some of which, as they become senile, sleep only through the tail end of winter, and den up so hungry that they awake in the spring in a pretty desperate condition.

Bears' Great Strength

The strength of the bears is beyond all belief. The polar bear is probably the strongest and most dangerous of the lot, a narrow-eyed, long-nosed beast, which can never be trusted. No wonder, considering his environment ! But next to him comes the grizzly, which is immensely powerful. A surveyor in the Lillouette described how a grizzly hit one of his pony

BROWN BEAR AND POLAR BEAR

Bears are animals of incredible strength but the polar bear is the strongest and craftiest of them all. The brown bear (above) in cold countries will hibernate in the true sense.



boys, and threw horse and rider clean into the air.

The Alaska brown bear is the biggest bear in the world, but he is a carrion and fish eater, and has neither heart nor courage. The grizzly, on the other hand, is a fine and courageous animal, and a gentleman, but in view of his immense strength he is best left alone.

With regard to the strength and fighting powers of animals, one might wish to know how the grizzly, the lion and the tiger would compare. So far as evidence goes, the tiger will kill the lion, but the grizzly would make short work of either of them. Where the polar bear comes in, we have no evidence at all, but we would feel disposed to back the grizzly in view of his immensely developed forelegs.

Real Hibernation

Proceeding with hibernation, it has already been inferred that except in circumpolar regions it is mainly a matter of convenience and necessity, which can be dispensed with when circumstances permit. In Great Britain, there are few real hibernators, excepting the mice, the bats and the reptiles. A good example is the hedgehog, which, given a proper chance, hibernates in the true sense—generally down a rabbit hole or under an upturned root, in any convenient cranny he stumbles across. He drags in a surprising quantity of leaves and grass to keep out the draughts, apart from the leaves he has impaled on his quills during his autumn rambles.

The writer once dug out a hibernating hedgehog, and the amount of bedding was almost beyond belief. When he arrived above ground he remained fast asleep, almost cold, and in effect more dead than alive. He was left in the wind a minute or two and he gradually roused, and finally gathered sufficient energy to creep back into his hole. So all his leaves and rubbish were pushed in after him and he was left to continue his dreams.

In East Lothian, the hedgehogs used to enter the writer's garden by the hen hole in the garden wall, and hibernate under the hen-house. One of them thought he would

CURLING UP FOR THE WINTER

Hedgehogs hibernate very thoroughly, making a covering of leaves and grass in some convenient hole. As a rule, only excessive cold will wake this animal from its winter sleep.

DORMOUSE—AWAKE

When awake the dormouse is a pretty little creature with large bright eyes. In the autumn he builds himself a cosy nest and sleeps the winter through, occasionally waking to emerge and eat a little food.

like to sleep among some sacks in the motor house, and made himself very cosy there, but his bed was so unclean that he had to be ejected. He then decided to sleep in a box-shaped affair where the children's bantams roosted, but the bantams took exception to his company, and again he had to be turned out. Finally, he was put into a tea chest with lots of hay and leaves, and there he slept obliviously in the potting shed till the joyous spring returned. Normally, if a hibernating hedgehog is flooded or frozen out of his winter quarters, he does not live to see the spring.

In the case of the squirrel and most of the rodents, hibernation is a very light-hearted affair. They are all food-hoarders, for their little bodies could not carry them through so long a period without sustenance. They retire to their own special warm quarters, and there they remain for many weeks, but they have their food dumps of grain or nuts or fungi at their elbows. They sleep for a few hours then nibble for a few minutes and sleep again.

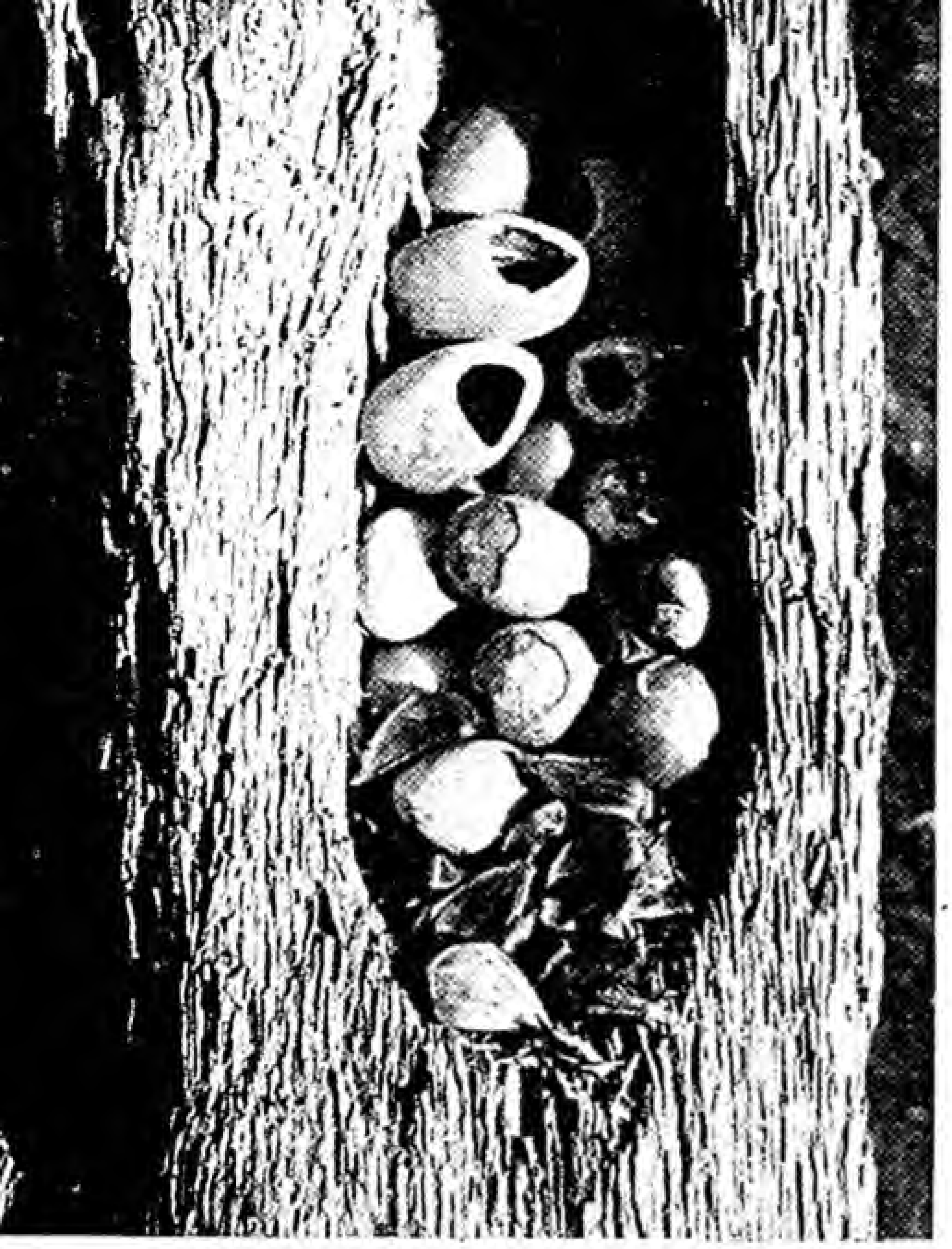
Amazing Store-rooms

The food dumps of some of the smallest rodents are really surprising. A mouse may have his house in an upturned root, but that root is a labyrinth of passages, and every passage serves as a store-room. Not only that; but other passages run out under the dead leaves, and along these he has his store-rooms and his nibbling places. It only shows how abundant is the autumn harvest, and how even the smaller creatures make use of it. Those who do not store lay on fat during the harvest days.

The squirrel also hibernates and is a food hoarder, but in accordance with his character he does it all in a heedless and devil-may-care manner.

During the lush days of autumn, when the leaves are drifting and the gossamer hangs, squirrels bury their nuts along every moss bank and leaf brae, thousands of them from dawn till dusk, but it is hard to believe that so heedless a little character remembers his burial grounds. Very well then. If the nuts remain in the ground they may grow into trees which will support his children and his children's children—a species of life insurance. At any rate he has done his best, and as the weather becomes colder his days become shorter, till one day it is very cold indeed, and he does not get up. He curls his tail round his nose and there he sleeps in a compact ball, possibly for several days, but one day he wakens to find the sun shining through the slit in his tree trunk, and, blinking sleepily, up he gets.

He goes to search the leaf banks where he has a hazy notion that he buried some



WINTER FOOD STORE
Fieldmouse's winter hoard of beech and hazel nuts secreted in the hollow of a tree. These provide food for its periods of activity during mild spells in the winter, as it only hibernates in severe weather.

beech mast, digs up three or four, nibbles them, disturbs a woodcock, and finally scuttles back to bed, uttering volleys of abuse at no one in particular. He does not seem to care very much whether he hibernates or not. As for systematic storage—it is difficult to believe that the squirrel is mentally capable of it!

Badgers' Winter Quarters

Badgers follow much the same lines, except that they are not so light-hearted in life. In late autumn, they fill their immense warrens with grass or bracken to exclude the cold. When really cold weather comes, they close the mouths of their holes to an aperture scarcely sufficient to admit a man's three fingers, and deep in the bowels of the earth they sleep, sucking their thumbs, until a warm day calls them out to nose for bulbs. Even in the high Grampians, one may see the tracks of badgers in the snow the winter through, so that it is a mistake to say that they sleep the winter away.

Have you ever picked up a little sleeping dormouse? He will lie curled up in the palm of your hand, a very pretty little creature, supremely at ease. But the coldness of his tiny body will strike through your hand although he is actually breathing and alive. That is *true* hibernation—a state so near to death that the merest breath will bridge it. Perhaps they are lucky in this. Most of those who hibernate die in their sleep, particularly when old age comes upon them. They simply do not waken to see the glorious spring.

Why Beavers Build

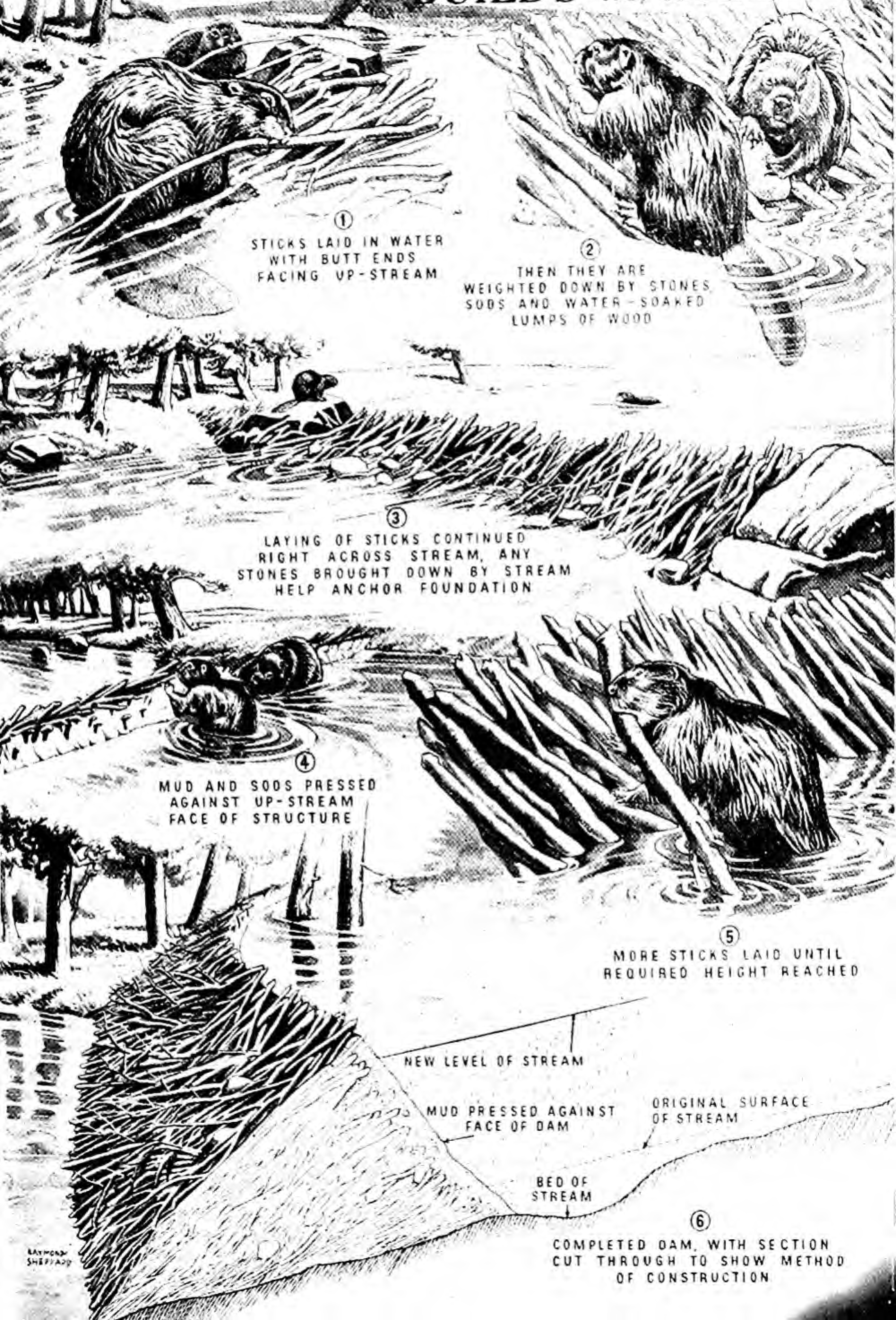
The beaver does not hibernate at all, though it has been written of many times as belonging to that class. He is purely a food-hoarder, and could not live through the winter in many of the cold countries he inhabits without deep water at his disposal. Hence the beaver dam, an artificial structure which he makes by damming the stream—any tiny stream he decides to live on.

Other beavers follow him, more dams are built, repairs and extensions go on, till in some places one can travel all day by canoe along what appears to be a series of natural lakes, but which is really the work of generation after generation of beavers.

As winter approaches, the beavers store the green branches on which they are to feed at the bottom of their ponds. How they prevent them from floating is not known, though it is an old fallacy that they suck the air out of them. In due course the pond freezes over, and now we come to another point—the beaver could not live without his lodge or his bank burrow. In his lodge (a huge island of sticks) he has his living chambers above ice level, and the roof is sufficiently porous to admit the small amount of air he needs. Its entrances and exits are below ice level, so that he can dive down to his store of food lying on the bottom. The bank burrow is on similar lines—bedrooms and sitting-rooms above the ice, front and back doors below it, but here he could get no air at all unless special provision were made.

In some way—no one knows for certain

How the BEAVER BUILDS its DAM



how—he constructs a tiny shaft, no bigger than a mouse hole, upwards from the ceiling of the dining-room to the world without. The hole is too small to admit an enemy, but to make doubly sure the beavers bury the outlet under a pile of sticks, which soon become covered with snow and are quite unnoticeable. So, while the wolves range and the blizzards rage, the beavers live their winter lives unseen and unsuspected with their larders at their doors.

Thus it is quite clear that there are food-hoarders, which may hibernate partially, and others which hibernate in the true sense. The latter generally fatten up to an alarming extent during the autumn harvests; in other words, they carry their store-rooms on their backs.

Weakened Digestions

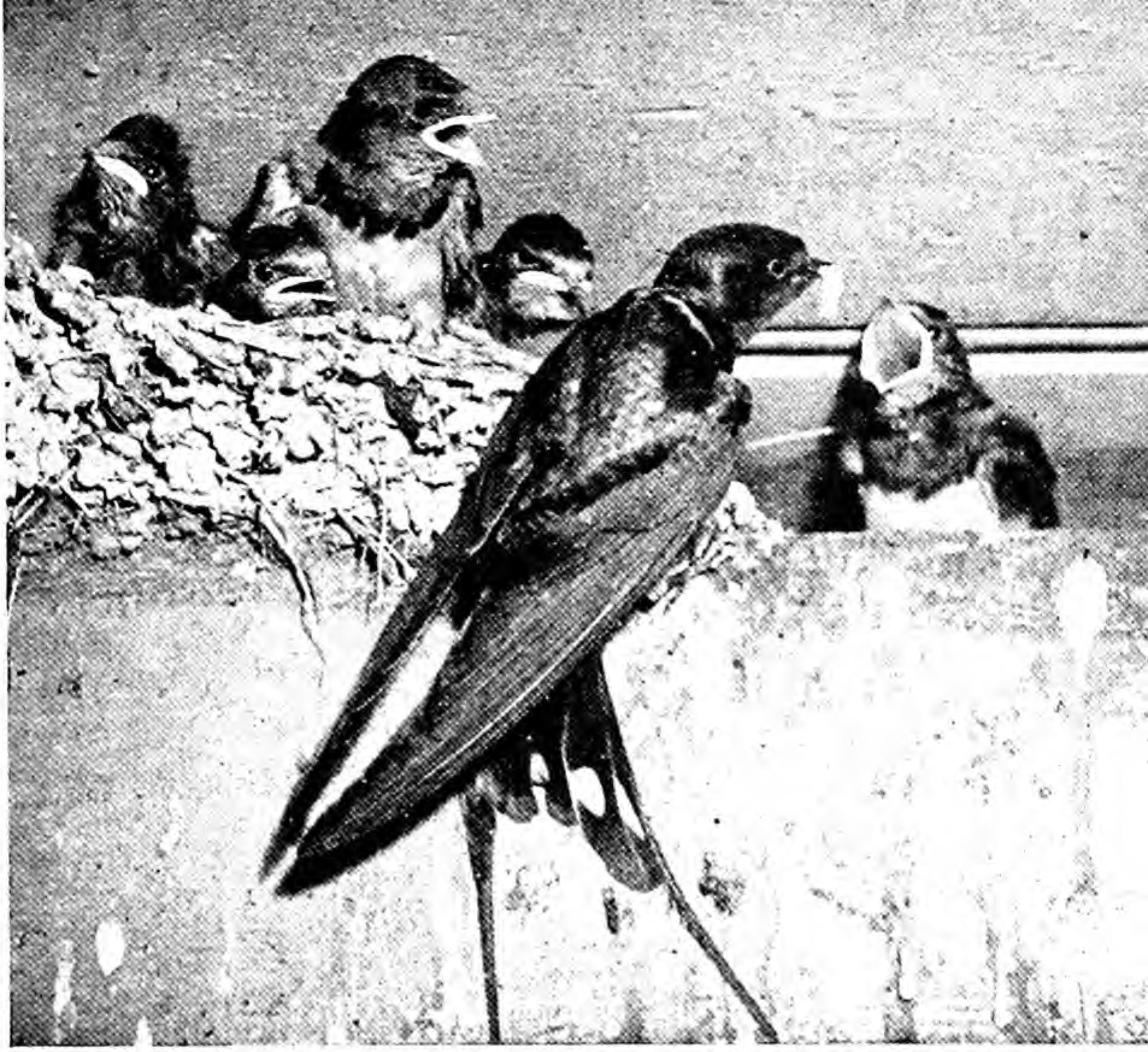
When those which hibernate in the true sense wake up in the spring their digestive organs are very near a state of exhaustion, and a heavy meal would probably prove fatal. Nature has her own method of dealing with this, for their feet have become so tender that they cannot forage far. Just a hasty mouthful and back to bed again, and even that mouthful must be cautiously chosen, for their mouths too have become tender by disuse.

How do wild animals die under normal circumstances? We have been apt rather to regard the closing chapters of their lives in colours of agony, but everything depends on circumstances. Where, for example, wolves range for game, few deer live to grow old; similarly, where foxes are numerous, few hares live beyond the zenith of their powers. With these hunted animals, it is merely a matter of how long they can hold out until the beam is tipped, while others living more sheltered lives, such as the majority of small birds in Britain, die naturally and peacefully, and most of them in their sleep.

The writer has seen old otters, grey-muzzled, and stone blind. Also old hinds wandering about the straths in such a toothless and pitiful state that the snow accumulated on their backs, and they had not the energy to shake themselves free. There are old blind seals, guarded and shepherded by their herds, and old blind buffaloes, which, in spite of their infirmities, lead the herds till their dying day.

BADGERS EMERGING FROM WARREN

Badgers, seen below, sleep during the winter months after having prepared their warrens, or earths, during the autumn with grass or bracken. On a warm day, however, they may emerge to nose for bulbs, as they are not true hibernators and seldom sleep the winter through.



SWALLOW AND YOUNG

Young swallows are seen above being fed by the parent-bird in their nest beneath the eaves. In ancient days it was believed that they hibernated in mud during the winter. Actually, they are migratory birds and travel south in autumn to summer skies.

Animals, in most cases, die tragically, but we must not let our imagination run riot on this. Death has really no meaning in the wilderness—no more than the changing of the wind, or the fading of a flower.

Truly they strive with all their power to avoid death. They know fear in all its extremities. There is the primeval urge to live, but death as an order, or as an absence of all order, is infinitely and immensely beyond their powers of comprehension.

A hind will tap her dead calf with a dainty, polished fore-hoof, and when he does not move go away to quite another part of the woods, where she was accustomed to seeing him, and search for him there. This still, cold, little creature lying in the leaves is not the merry, active little spirit which followed her yesterday, and this seems to be about the level of things among wild animals.

Behaviour of Birds

The behaviour of birds has interested mankind throughout the ages. Aristotle first wrote the proverb, "One swallow does not make a summer, nor one fine day." To Aristotle also must be traced the belief, almost universally held by the old naturalists, that swallows hibernated in winter. Pliny, writing of the kingfisher, said that this bird "breeds in winter, at the season called the Halcyon days, wherein the sea is calm." The people of that time believed that the kingfisher made a nest of fish bones and launched it on the sea, and that during

the time the bird was brooding her eggs a profound calm reigned.

These, and other strange beliefs, showed that the people of olden times appreciated the charm of birds, although they did not study them so closely or accurately as we do. We now know that the swallow does not hibernate in the mud beneath some mere or lake, and that the kingfisher does not put to sea on her frail nest, but we have learnt other marvels of the bird world of which the ancients were ignorant.

In their courtship and mating, their nest-building and their territories, birds are a continued source of interest and delight. Does a bird think? Does it reason? How much of its behaviour is instinctive and how much reasoned?

Before these questions can be answered, it is well to realize that in the bird world there are a great many types, a great many stages in evolution. There is as great a difference as between the highest type of civilized being and the most primitive savage. Some birds are heavy, dull and stupid; others are extremely intelligent; some are saurian in habit, others are ethereal and delicate. The world of a bird is, we may be sure, very different from the world of man. The bird is free as air; man is held fast to earth by the laws of gravity. Compare the flight of an eagle over the hills with the laboured progress of a man. An eagle can cover in a minute, without effort, a distance a man, under most favourable conditions, can cover in an hour, and which under disadvantageous conditions it may take him several hours or even a day to cover on his own feet.

Instinct in Birds

There is undoubtedly much that is instinctive in the life of a bird, just as in the life of a man. Migration—that greatest

ARCTIC TERN ALIGHTING

These graceful birds are the greatest travellers in the world, for while some breed as far north as Spitsbergen, they winter on the shores of the Antarctic, thus covering the distance from Pole to Pole twice in a year. The picture shows the tern's powerful wings.

STARLINGS IN FLIGHT

Among the commonest of birds resident in the British Isles, starlings are often seen in massed flight, and such a flock on the wing is a memorable sight. These starlings are mostly continental birds; they mass in autumn and winter to roost in reed beds or on city buildings.

of all wonders—is, to a large extent at all events, instinctive. The fact that it is instinctive heightens this marvel, which has intrigued the minds of men through the ages. The more we know of migration the more astounding it seems.

Let us consider the migration of the Arctic tern, one of the most graceful members of a graceful family. This tern nests, in the Northern Hemisphere, from Scotland northward to Spitsbergen and North-East Land, where ice floes drift around the coast and the hills are deep in snow on the longest day. Here the Arctic terns nest by the light of the midnight sun which is not, as seen from the North Cape of Norway, a dull, glowing orb on the northern horizon but a dazzling disc, which shines warmly on a north-facing slope so that, provided he chooses snow-free ground, the explorer may here bask or even sleep, with as much comfort as on a Scottish hill.

Under these conditions the most northerly of the nesting Arctic terns have their summer home. Dependent as these birds are for their food on an open ocean, it may be readily understood why the terns should migrate southward at the close of summer. One might imagine that they would fly south to the sunlit waters of the coasts of Spain or West Africa, there to fish in comfort during the long months when the Arctic Ocean is held fast in the grip of the ice, and when the spray, whipped up by the gale where the water is still open, may freeze before it has reached the bridge of a vessel, the particles of solid ice rattling against it like small shot.

Arctic to Antarctic

But does the Arctic tern winter above the blue waters of the seas which approach the tropics? If the evidence of the last twenty-five years is to be believed, the birds continue their southward flight until they have crossed the equator; then, still flying toward the south, they enter the season of spring in the Southern Hemisphere. Still moving south, they reach the edge of the Antarctic ice, where they winter. The first Arctic tern that was shot by an Antarctic expedition in these latitudes was believed, so incredible was the length of the flight, to have been of a species allied to the Arctic tern of the Northern Hemisphere. But since then, further specimens have been obtained and the feeling now among scientists is that the

bird which winters in the Antarctic summer is the same bird that has nested in the Arctic summer. Thus the flight of the Arctic tern may be said to extend literally from Pole to Pole.

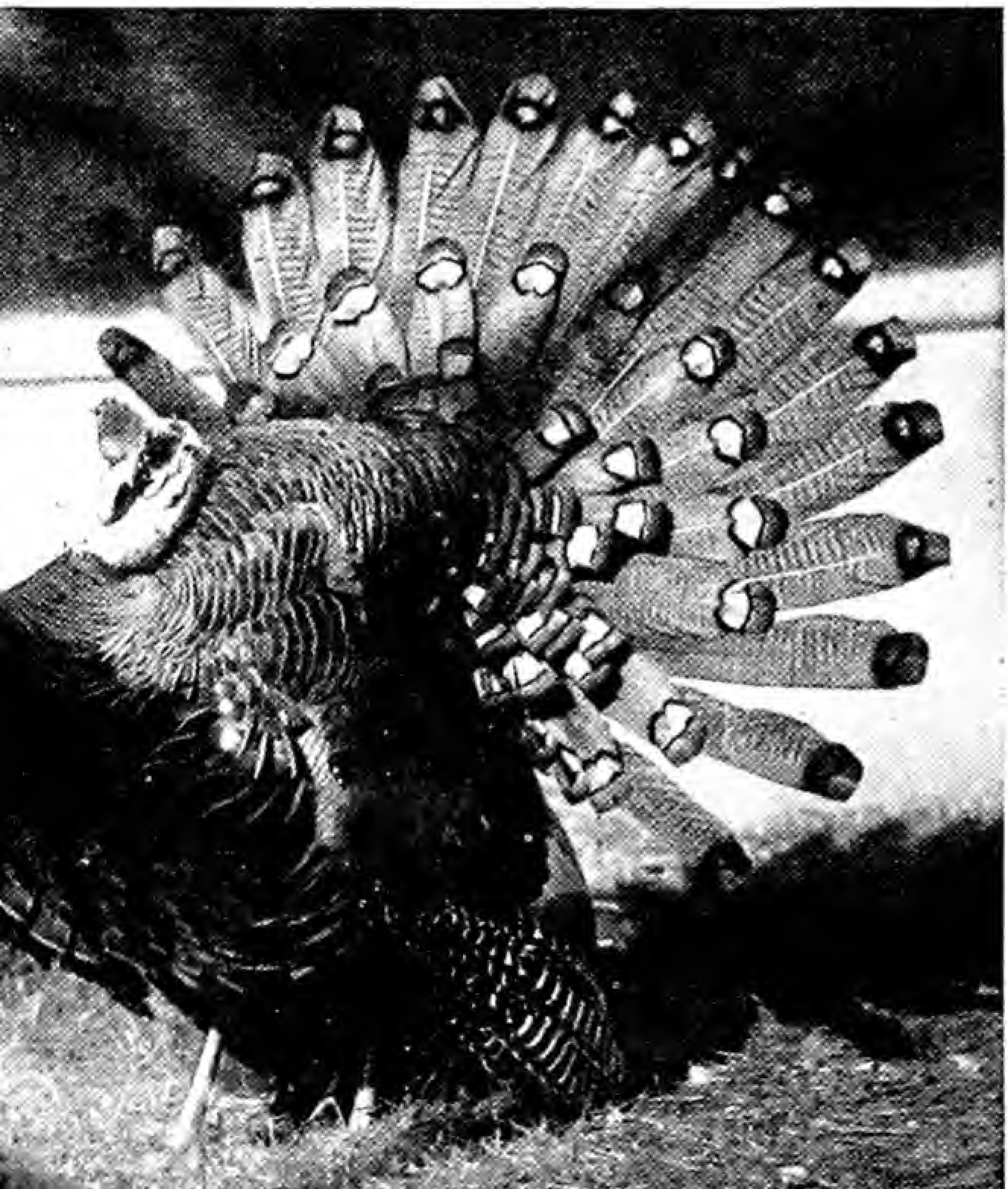
Let us consider the conditions under which, because of this great flight, the Arctic tern lives. Warmth is evidently distasteful to it, for both in summer and in winter (winter in the Northern Hemisphere) it is in the neighbourhood of ice. But—a remarkable thing—it thus lives in perpetual daylight. In Spitsbergen, in summer, it nests without darkness or even dusk. In its winter haunts, at the edge of the Antarctic ice-field, it has again continual daylight, and sunshine, both night and day, for perhaps a week at a time. This tern may, therefore, be held to be, if not a warmth worshipper, at least a sun worshipper.

Compared with that great flight of the Arctic tern the migrations of other birds are small, yet even they are of great wonder. The swallow which arrives at the barn, the house martins which arrive at the house beneath the eaves of which they have nested in past years, have travelled far. They have wintered in South Africa, and their northward journey has been a leisurely one, following the tide of spring as it flows slowly northward. The main tide of bird migration flows in autumn towards the south and in spring towards the north, but there are exceptions. These exceptions occur chiefly, if not wholely, among sea birds, which on occasion have been known to migrate at the approach of winter towards the east, and even towards the north-east. Whether these unusual flights have been deliberate, or whether they have been the result of heavy south-west and west gales, which often prevail at that season, is not known for certain.

Fish Eaters

True sea birds are hardy, and provided their food is plentiful they are indifferent to the weather. An abundance of fish attracts that largest of British sea birds, the gannet, called in Scotland the solan. Thus in the winter of 1945/46, Lerwick harbour, in the Shetland Islands, was the temporary home of flocks of gannets, which dived throughout the daylight hours upon the great shoals of the young of the coal-fish which were then swimming in the sea-waters. Under ordinary conditions, a gannet does not approach the shore near a harbour, yet these birds were diving without fear into the waters of a busy seaport.

One of the most attractive features in bird life is the courtship display. In migrants, the people of Britain may not see



OCELLATED TURKEY DISPLAYING

Courtship display in birds takes many different forms but usually the male bird postures and struts before the female. The handsome ocellated turkey spreads his tail feathers.

HOW BIRDS BUILD A NEST

Drawing designed to show the different stages in nest building by a pair of thrushes. After a site has been selected, the birds make many journeys back and forth with a variety of materials, including roots and mosses. Finally, the nest is lined with mud.

the courtship, which may have taken place thousands of miles to the south of these islands. The leading part in the courtship of a pair of birds is taken usually by the male, but there are exceptions to this rule. The red-necked phalarope, a bird rather smaller than a snipe and nesting only in the northern and western districts of Britain, is one of these exceptions. The female is larger than the male and of a brighter plumage—she is indeed a bird of rare beauty. It is she who does the courting, and not only that, for she is believed to be at times polyandrous—that is having several husbands.

Unnatural Mothers

The male phalarope is given the work of hatching out the eggs. So far as is known the female takes no part in these duties, nor does she even visit the male to see how he is faring. The dotterel also is a bird that reverses the usual processes of courtship, and here again the male hatches unassisted his wife's eggs. Nor does she visit him even on the great day when the eggs chip and the chicks emerge.

Most birds have a courtship which lasts only during a comparatively short time in each season. But the fulmar petrel seems to court throughout two springs and summers before the first egg of a pair of young birds is laid, and the courtship of a pair of young golden eagles would appear to last several years before the eyrie is built and the first eggs laid.

The courtship of the golden eagle is a breath-taking sight, both birds with closed wings rushing through the sky at tremendous speed, then turning, wheeling and gliding in a regal, stately manner, heedless of the raven, grey crow, or kestrel that may with impotent fury seek to chase them off its own particular territory. The writer on one occasion witnessed the actual mating of the golden eagle. This took place

GANNETS ON GRASSHOLM

Gannets leave the British Isles in the autumn for southern waters, travelling for long distances, often to the west coast of Africa. The date of their departure each year is remarkably regular. Grassholm Island is a bird sanctuary in Wales. Thousands of gannets nest there every year.

on a rocky pinnacle, the male mounting on the female's back and there maintaining his position with beats of his strong wings.

Bird Song

With courtship is closely associated song. As the Gaelic proverb has it, "Lonely is the country where no voice of bird is heard," and the song of birds has cheered many persons, even listeners who have been unable to name the song which they heard. In the British Isles bird song is heard to advantage. The British, as a nation, have been more forbearing toward birds than most: they have not shot or netted song-birds as some continental nations have done. Their woods resound with the songs of birds from February until June. What is the best bird singer in Britain? The nightingale would usually be given that honour, but there are some who think that the song of the blackbird is fully its equal.

There is a song of wild beauty which few people have heard, both because the singer is a rare and local bird and also because it seldom utters its song. The greenshank—the singer referred to—utters his song in the air, while he is flying fast backwards and forwards overhead. It is a song of extraordinary wildness, the flute-like whistles—deeper toned than the redshank's whistles—being uttered in sets of twos, the first two lower pitched than the second two.

Lord Grey and the Curlew

The distinguished naturalist and statesman, the late Viscount Grey of Fallodon, ranked the song of the curlew high among the songs of birds. In his book *The Charm of Birds*, he writes that this song conveyed to him the sense of happiness, past, present and to come. Grey's life was clouded towards its close by increasing blindness, and it is good to think that he was cheered by the songs of the curlews which nested near his home.

Most birds are day singers, but a few sing both by night and by day. In the latter class are the nightingale and the garden warbler. Between dawn and sunrise on a quiet and mild May morning is the best time to hear birds. The dawn chorus, as it has been sometimes named, ceases before sunrise, when the birds begin to set about the more practical business of breakfasting. But no bird breakfasts before he sings. The lark is perhaps the earliest singer, and in the Isle of Skye has been heard singing a few minutes after 1 a.m. by Summer

Time—that is, a few minutes after midnight by Greenwich Time.

Linked closely with singing is the territory of birds. Territory, during the nesting season at all events, is a sacred thing. A bird will fight, and if needs be die, for his territory. When a cock bird has selected a desirable pitch for his home, he will challenge, and do battle with, any other male which ventures to enter his territory. Sometimes a late snowfall confuses birds by obliterating landmarks on a territory. During May of the year 1923 a severe and prolonged snowstorm visited the Cairngorms, a high hill range which stands at the source of the River Dee in the Central Highlands of Scotland. During the last week of that May the writer was in one of the corries of Braeriach, where snow to the depth of three feet covered the ground, and from the hardness of the snow it was evident that it had lain there for at least a fortnight.

At that time the stock of ptarmigan on the Cairngorms was much larger than at the time this chapter is written, and the territory of the nesting pairs had been chosen before the coming of that exceptional storm. There must be marks on a hill which show a male ptarmigan the

boundaries of his territory. He must know the colour of the ground, the screes and boulders, the small streams and springs—a thousand things which tell him where he is. But in this snowy May the rocks, the streams and the Alpine vegetation were hidden by snow, and during the misty hours the writer spent in the corrie he saw how this snow had confused the ptarmigan, for there were frequent challenges, and fights and pursuits, and the sight was seen of two cock ptarmigan flying excitedly one after the other or side by side over the snowy expanse, which might well have been Spitsbergen in late May and not a hill of Scotland.

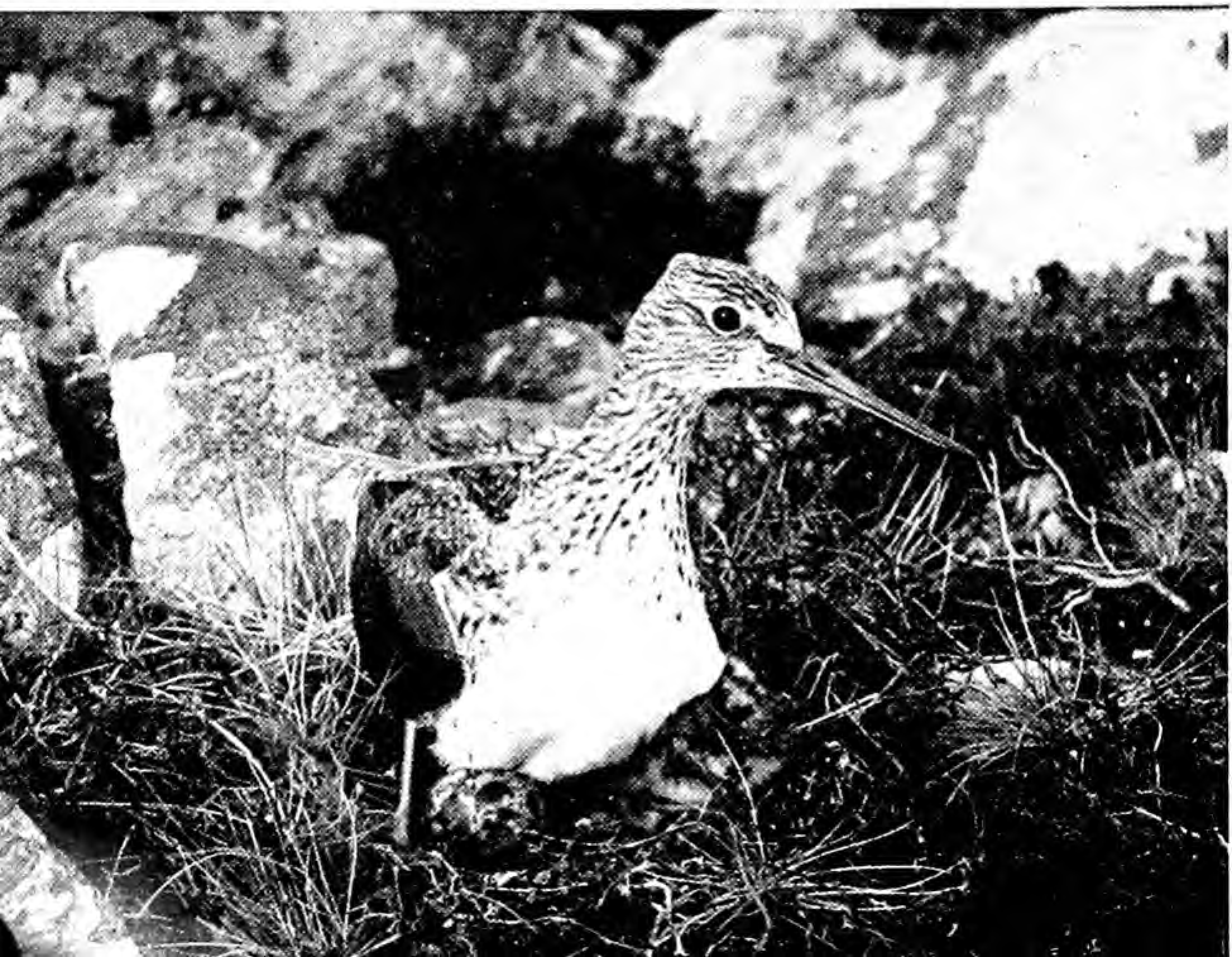
Territory of Robins

But the territory is not a thing of the nesting season only. In some cases there are territories in winter, but these belong not to a pair of birds, but to a single bird. It is a remarkable fact that a pair of robins, which have nested and have reared one or even two broods within a territory zealously guarded by both against other birds, should separate in autumn and take up territories of their own. Should the one robin then deliberately or unwittingly enter the territory of the other it is chased out with fury, the hen being fiercer than the cock. Throughout the winter, the two are intensely hostile to one another; at the approach of spring the hen with reluctance gradually accepts the advances of the cock and then they join territories, or form a new one.

The territory at the nesting place of sea birds is usually more circumscribed than that of land birds, for sea birds sometimes nest in immense colonies. The common guillemot, for instance, lays her single large egg on the bare rock only a few inches from her nearest neighbour. The guillemot's territory, therefore, consists merely of the actual part of the cliff where the egg is

WILD BIRD'S SONG

One of the sweetest and least known of bird singers is the greenshank, a member of the sandpiper family, named on account of its long olive-coloured legs. It sings while flying and its song is one of haunting beauty. The greenshank is a rare marshland bird.



TERRITORIAL CLAIMS

Territory is jealously guarded by birds, particularly during the nesting season, and the cock birds are always aggressive towards any hint of encroachment by newcomers. Aggression, however, is often a matter of display. When the holder of the territory adopts a threatening attitude the intruder usually departs. Above, black-headed gulls sparring.

brooded penguin-like upon the bird's feet. Compare this with the territory of a pair of golden eagles, which may consist of many square miles of hill, glen and corrie.

A male bird will, if needs be, defend his territory with his life, but the interloper usually retreats before the onslaughts of the rightful lord of the territory and no damage is done to either combatant beyond the loss of a few feathers.

Grateful Guillemot

Birds are quick to become tame, especially if in ill-health when found and nursed by a human friend. Sea birds suffer from crude oil floating on the ocean. This oil sickens or kills them. One winter day a guillemot was found on the shore very sick from oil poisoning and was taken home by a bird lover. The guillemot was washed and cleaned and was fed on small slices of fish. In eight days that wild bird had come to recognize its human benefactor, and ran to him with quivering wings, as it might have done to its mate.

From being a hardy sea bird, at home on the stormy ocean during the most severe winter weather, it became house-loving, if not house-trained. Its human friend owned a terrier, which had a cushion near the fire. The terrier good-naturedly allowed the guillemot to share the cushion, but soon the bird, with a singular lack of gratitude, would not allow the dog to come near the cushion, on which it sat, slowly moving round in order that all parts of its plumage should be equally warmed by the grateful heat of the fire.

One morning the guillemot's mistress (for the bird had by now become a household pet) reluctantly decided that she must say goodbye to her protégé, as fish was difficult to procure for it. She therefore took it down to the shore and placed it in a rock pool, thinking that the bird would be only too pleased to find itself once again in its natural element. But the guillemot lost no time in scrambling out of the water and set off home as fast as its clumsy legs could carry it, and when its mistress arrived there, was warming itself contentedly by the fire.

The reaction of a bird is even greater towards light than towards heat. It is light rather than heat that tells the early nesting birds that spring is at hand. The raven may

WILD BIRDS OF SEA AND ROCK

Sea-birds, like the puffin (above) often live in vast colonies on rocky coasts. The puffin's bill in the breeding season becomes greatly enlarged and brightly coloured, a form of courtship display. The puffin lays a single egg in a burrow often appropriated from a rabbit. The rock pigeon (seen below with young) nests in dark caves or in the open on grassy cliffs.

build or repair her nest when snow covers the land. The writer has seen purple sandpipers at the end of June on Prince Charles Foreland in Spitsbergen, under conditions so severe that the birds were compelled to remain at the margin of the tide because all the country inland from high-water mark was deep in snow. These birds had migrated from more temperate lands and although winter had not yet left their nesting island they knew, by the continuous daylight throughout the twenty-four hours, that it could not be long until the snow melted.

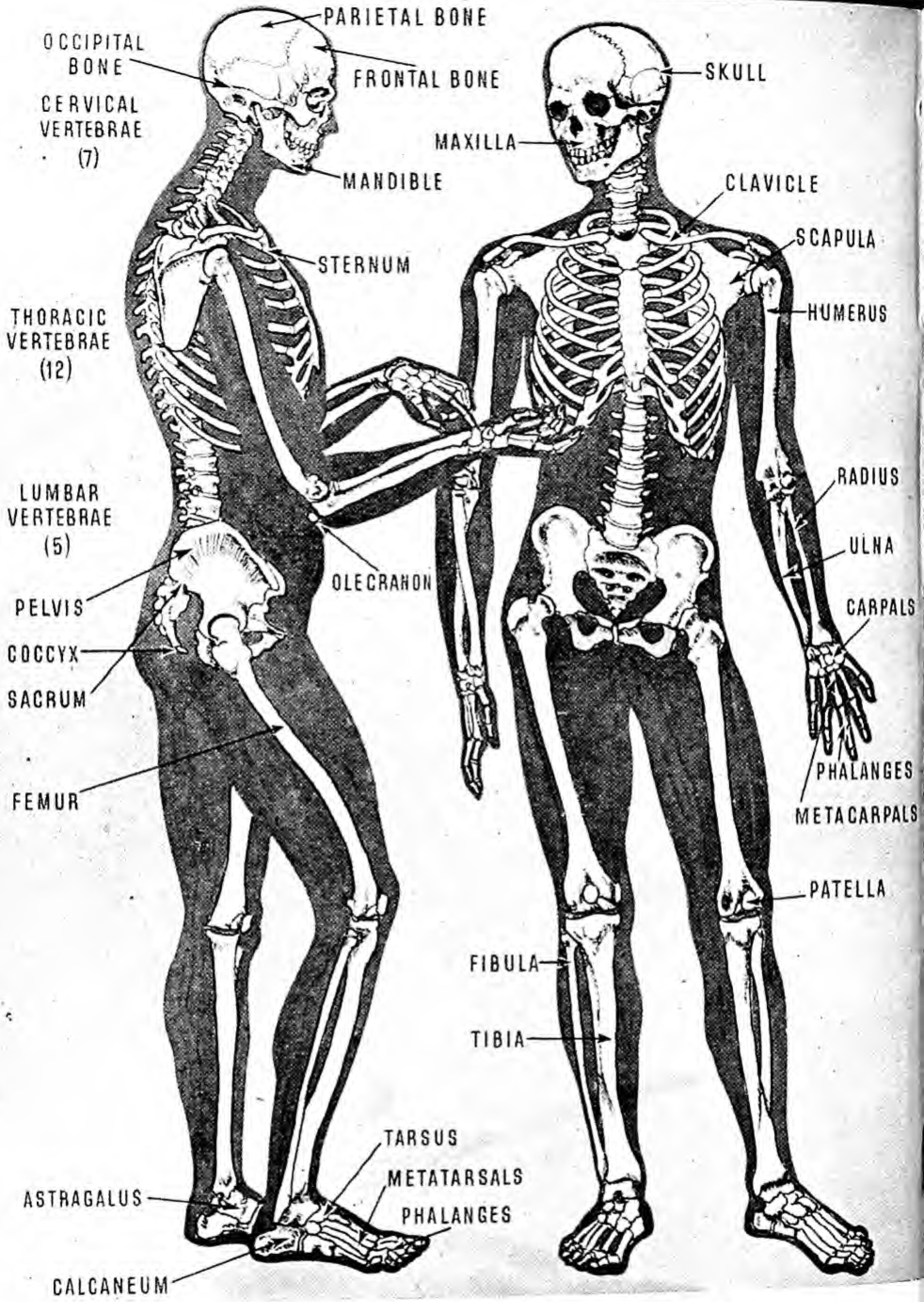
Why do the gannets regularly leave Hebridean waters almost to a day in October? The weather may be summer-like and the supply of fish more plentiful by far than in the early summer when they were nesting. It is probable that the gannets know by the declining actinic quality in the light that winter is near and take their departure accordingly.

Light has a powerful effect, as has been proved by experiments on the reproductive organs of birds; it is therefore the more remarkable that the wild rock pigeons which are found on some parts of the Scottish coasts should rear families continuously through the twelve months of the year.

Test Yourself

1. What are the impulses which cause animals to pack, and by what are they governed? Give reasons why animals collect together in this way.
2. Which is the most powerful of the fur-bearers?
3. Why is the polecat called the foumart and the pine marten called the sweetmart?
4. Of all warm-blooded animals, which take the heaviest toll of human life?
5. In what ways is the caribou so admirably adapted for migration?
6. What is the difference between true hibernation and the storage habit?
7. Can you suggest any reasons why the arctic tern should travel so far when it seeks its winter quarters?
8. Is it true to say that among birds the cock is the more brightly plumaged? Give some examples of courtship display in birds.

Answers will be found at the end of the book.



HUMAN SKELETON—FRONT AND SIDE VIEWS

A skeleton provides support, protects the internal organs and allows for active movement. Note that the bones of the skull and those of the sacrum and pelvis are fused together to give rigidity. The others are bound together with ligaments and many of them are hinged so that they can be moved by the muscles attached to them.

CHAPTER VIII

THE HUMAN BODY

MAN is pleased to call himself the lord of creation. Biologists put it more crudely and say that he is the highest type of mammal. That means that he is a vertebrate who feeds his young in their immaturity, from the secretion of special glands, the mammae or breasts; that he is the last product of evolution and, therefore, the highest. Is this logic, or may it not be conceit? Does it follow that the latest in time is the highest or best? Not necessarily, for no one assumes, not even the best writer of our day, that he is better than Shakespeare, nor that the most modern office building is better than Westminster Abbey or Durham Cathedral.

Nor does "highest" mean the most complicated. Man actually is not as highly specialized as other animals. What it means is that man has more power over his environment than any other animal. Other animals take things as they come. A lion accepts his jungle, a plant its rock crevice. Not so man. Starting perhaps in the jungle, he invades the open country. He inhabits even the deserts, the tundras of the Arctic Circle, the islands of tropical seas and those of the bleak wind-swept or fogbound islands near the poles. Not content with that, he invades the air with his aeroplanes and the sea with his submarines. He is in process of beating every other animal at its own game. In fact, evolutionally speaking, that *is* his game: getting control over his natural environment.

Importance of Bodily Structure

Now, apart from all philosophical and ethical considerations, apart from considerations of the development of mind, it cannot be doubted that his body is one of the chief means by which he has gained that control. It is fitted for that control by its structure, taking that word in its widest sense. Of course, the development of the brain is the chief thing which gives him his supremacy, but a brain unsupported and unprotected would be a useless affair. A brain kept only a few inches above the ground (as is that of a dog) would be circumscribed in its usefulness. A brain without the eyes (and to a less extent without the ears) would be at a hopeless disadvantage. Man's upright position has given him the ascendancy in the struggle for existence. It gives him the advantage of a more flexible and wider range of vision, freer movement of the head and trunk, and above all, by liberating the two fore limbs has provided him with hands—those most useful tools and weapons. In fact, man owes part of his dominance to his upright posture, in other words, to his bones.

Queer! We are apt to look upon bones much as an engineer looks upon the steel skeleton of a skyscraper, something upon which to hang an assemblage of organs as an engineer fixes windows and floors and ceilings upon a steel framework. The bones certainly are a framework, but, as we shall see, how much more!

We can best get an idea of the value of stiffening material (which is partly what bones are) by contemplating a jelly-fish. We have seen them in the sea, floating about as the currents waft them, well adapted to their surroundings. But, cast on the shore, what a helpless thing a jelly-fish is. It is buoyed up when in sea water, by the water, but in the air, with its low buoyancy, it just flops.

Now, as is stated in earlier chapters, the living parts of all plants and animals are made up of protoplasm, a fluid with something like the consistency of jelly—a weak, flabby sort of material, very like that of the jelly-fish. And these plants and animals are made up of cells, and very often the cell is wholly protoplasm. Now in man there are perhaps three hundred and fifty billion (i.e., three hundred and fifty million million) of these cells. If there were not stiffening material around which to dress them and connecting material to tie them

together, man would be as helpless as a jelly-fish cast up on the sea shore.

The stiffening material in animals may be put outside the body or inside. When outside it is called an exoskeleton (examples, beetles and all other insects, lobsters and all other Crustacea and so on). When inside, it is called an endoskeleton. This latter plan we and all the vertebrates follow. An exoskeleton has its advantages, especially for smallish animals or those living in the sea. But it has grave disadvantages. It puts a limit to growth. A crab has to retire to a secluded spot every now and then and cast off its outer coat and, until it has grown a new one some sizes larger, it is completely defenceless. Most middle-aged persons would be put to it to wear the clothes of their youth, and an exoskeleton is like a suit of armour, it does not stretch.

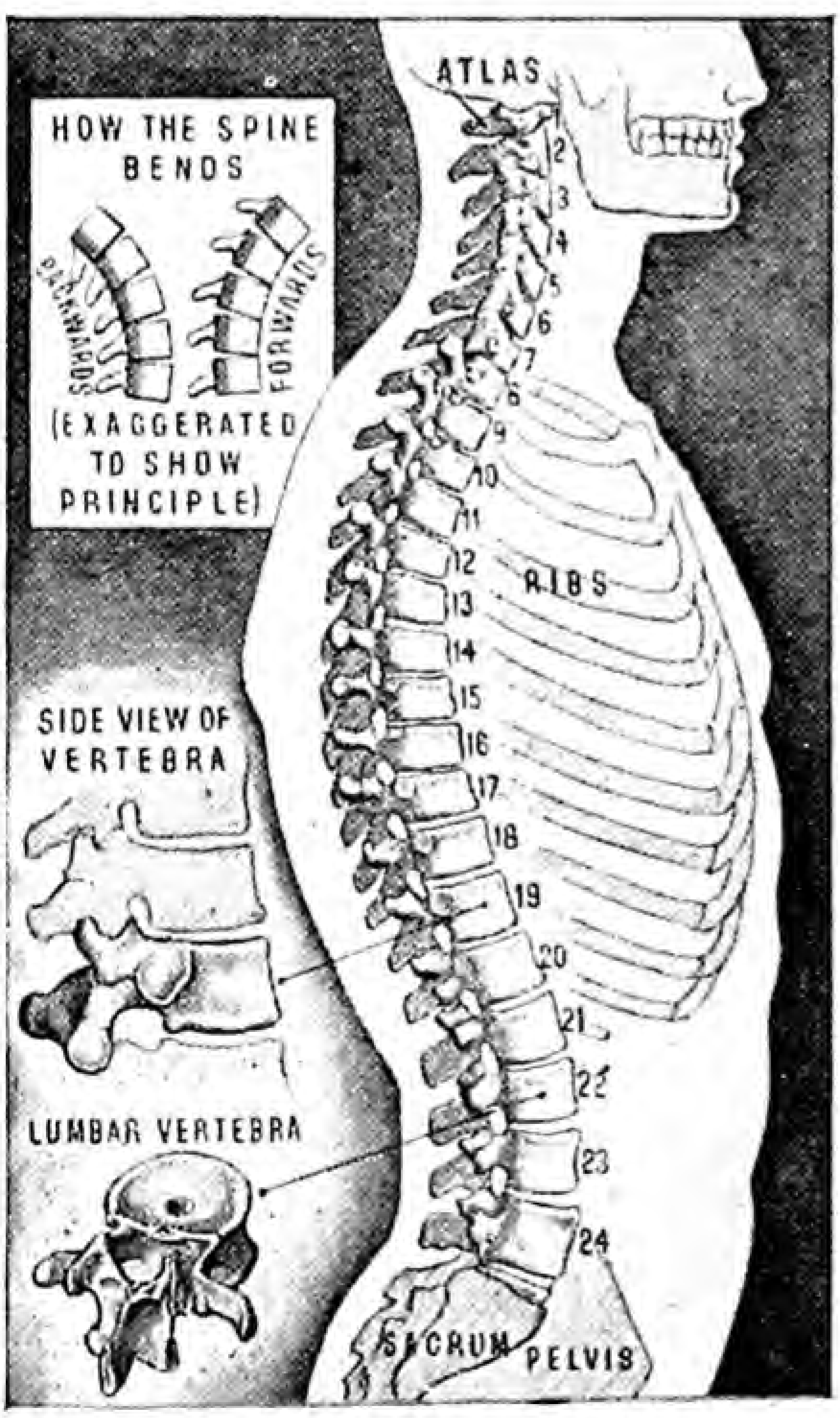
The disadvantage of an exoskeleton can be guessed from our trouble with our brain boxes. They are almost exoskeletons for the brain. Now, the brain has to grow, and grow after birth. A big brain box is an essential. So babies have to be born very immature, or their brain boxes would never get through the birth canal; and they have to be born with incomplete brain boxes, boxes with soft parts to them (the fontanelles) which do not harden until later in life—sometimes never at all. A brain box without fontanelles produces an idiot. A brilliant statement of when exoskeletons would be an advantage is to be read in H. G. Wells's famous book *First Men in the Moon.*

Levers for the Muscles

But skeletons are not only stiffening material. They are something for the muscles to pull upon. The bones act as levers, the muscles pull on them and propel us through space when we walk or run, or enable us to throw things at wild and other animals, or, perhaps, merely maintain our upright posture. A man whose backbone loses its rigidity (as in *caries* and *osteoporosis* of the spine) simply crumples on himself. He loses his upright posture.

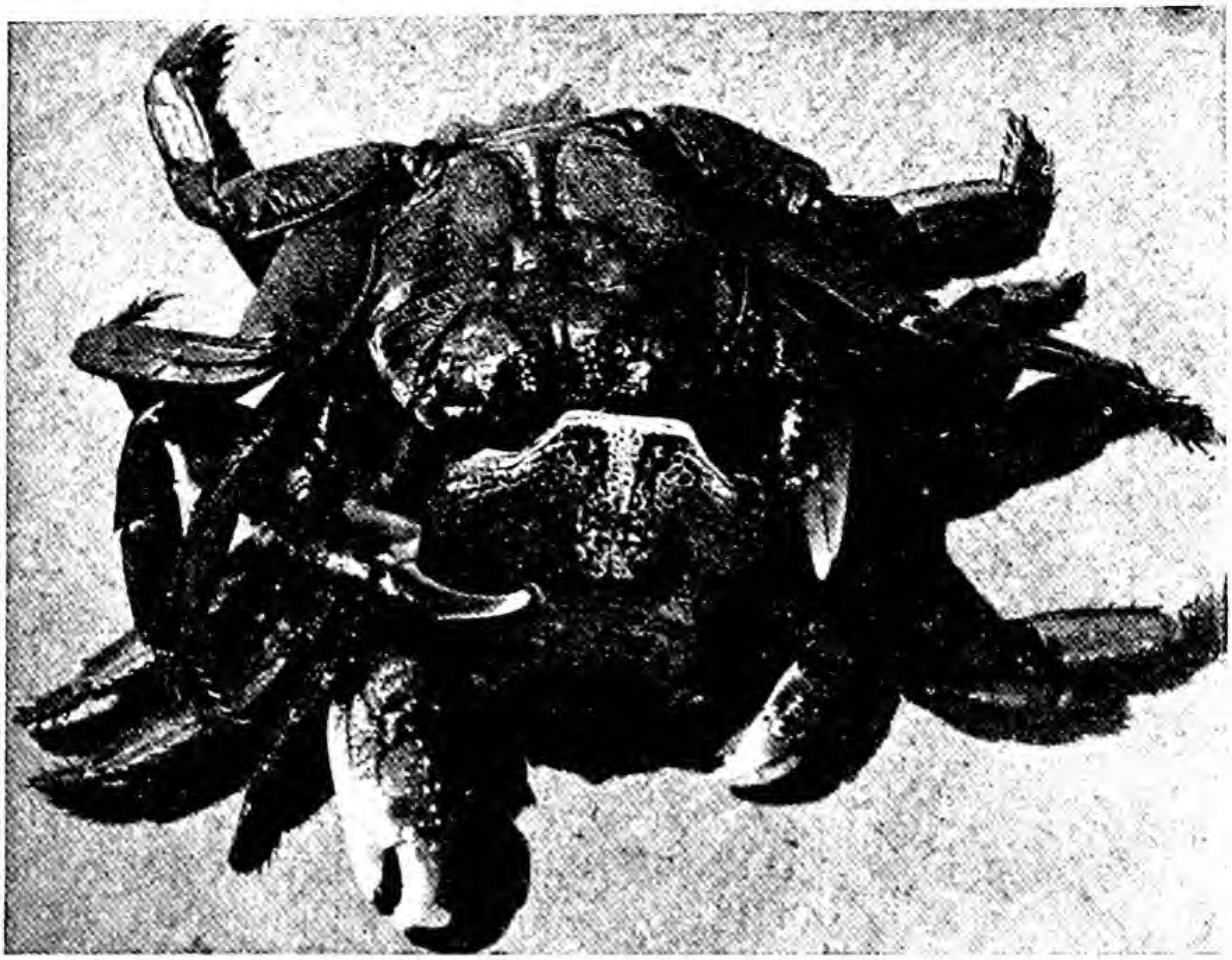
Still further. The bones are not only stiffening material and levers, but they are factories of all the red and some of the white corpuscles floating round in the blood (twenty-five billion red, and thirty-five thousand million white). The red marrow factories of the bones turn out anything from a quarter to one billion spare parts per day.

Bones consist of thirty per cent animal matter, mainly collagen, from which glue is made (collagen means glue-making), and seventy per cent mineral matter. This mineral matter is largely calcium phosphate, with some calcium carbonate and fluoride and a little magnesium phosphate. (That is why bones make good soil fertilizers, for plants need calcium—i.e., lime—and phosphates.) The mineral matter imparts strength to the bones, and the more there is, the harder and stronger the bone.



MAN'S SPINAL COLUMN

The backbone is made up of separate vertebrae which give rigidity to the body and protect the internal organs. Each vertebra has a hollow arch of bone at the back through which the nerve cord passes.



INTERRUPTED GROWTH

The arthropod animals carry inelastic skeletons outside their bodies. Such tough outer casings are valuable for protection but they impede growth. Therefore the crab shown above is casting off its shell in preparation for a period of active growth.

Bones may be flat, like those of the skull, or long, like those of the limbs, or intermediate between the two. The long bones have hollow shafts, the walls of which are made of compact bone, while the heads consist of spongy (or cancellous) bone. Each of these arrangements is for strength. The lines of stress and tension in a bone (such as the thigh bone) correspond to those in which an engineer would put his struts (to take the stresses) and his tension members (to take the tensions). Nature in this anticipated man and his mathematics and engineering, by millions of years.

Our bones, however, are not bones from the beginning. They are sketched out quite early in life as gristle, with the exception of those of the skull, which are sketched out in membranous material. Not until long after the developing baby is recognizably a human baby, does this gristle begin to be transformed into bones, that is, at about the fifth to sixth month of life in the womb. And not until a child has ceased growing at, say, the age of eighteen or even later, is all this gristle transformed into true bone. In fact, the growing parts of bones are gristle, and this gristle is continually being added to and as continually being transformed into bone until the body finishes growing and becomes truly adult.

Cause of Rickets

Sometimes in babies, or even in older children, owing to improper feeding and lack of sunlight, this process of turning gristle into bone goes awry, and we have a condition called rickets. This trouble, once common in Britain—so common indeed that rickets was known on the Continent

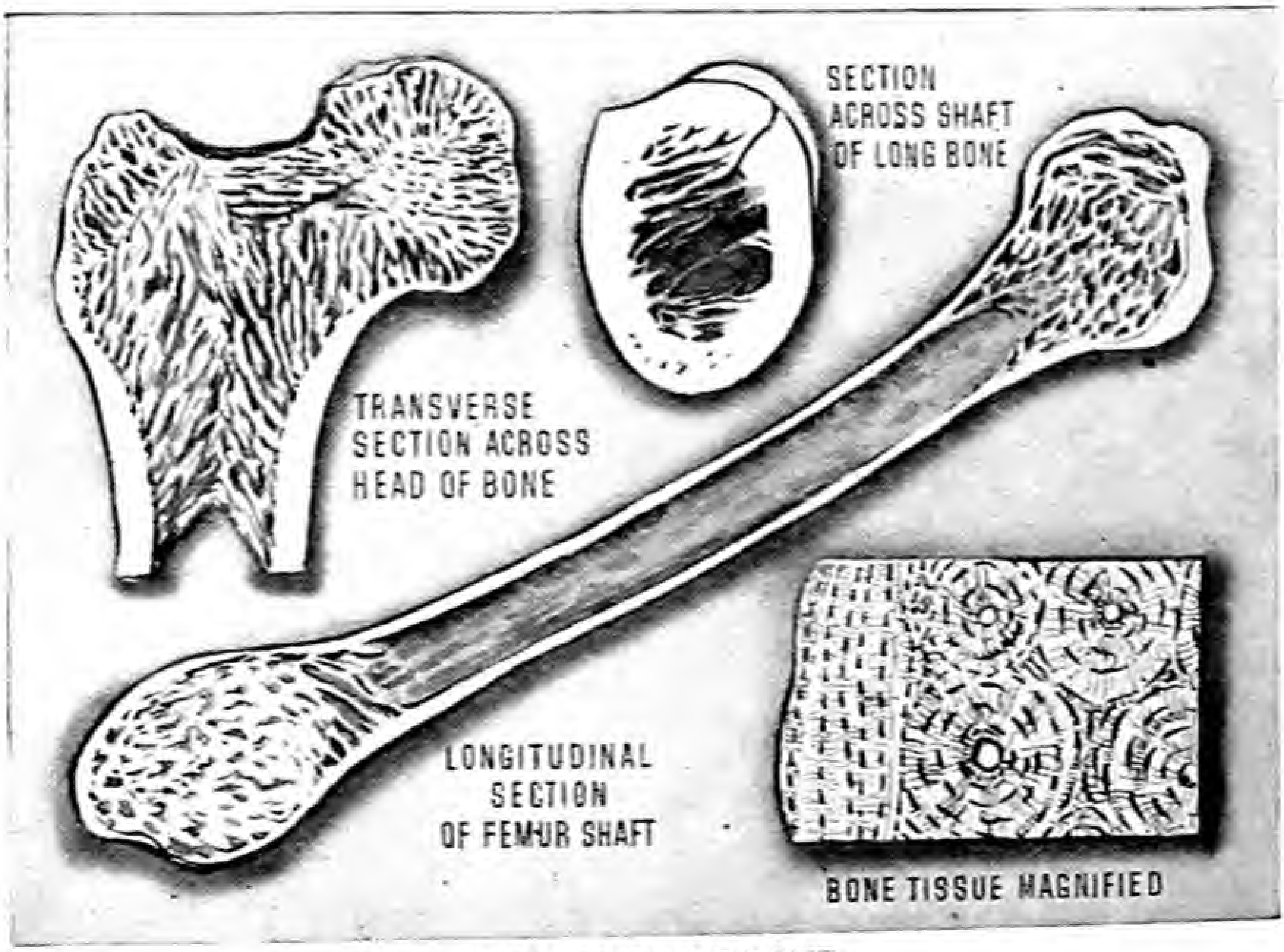
as the "English disease"—is now, under modern conditions of food and general hygiene, disappearing.

We must not, however, look upon bones, even adult and well formed bones, as dead matter. They are living and breathing and changing all the time, so that throughout life we have to continue the good feeding and attention to hygiene which are essential to the formation of strong, healthy bones in childhood. One must eat plenty of sources of calcium (milk, cheese and fish) and of the calcifying (i.e., bone manufacturing) vitamin, which we can get from herrings, salmon and the fat fish in general or by exposure to sunlight. Otherwise, our bones will soften and become rickety (osteomalacic). In extreme cases of deficiency they become full of holes (osteoporotic) and will collapse under the stresses of holding up the weight of the body, but this condition is rare nowadays in civilized countries.

During times when there is a need for extra calcium, for instance, when a woman is producing or nursing a baby, or during rapid growth, care should be taken to see that there are extra good sources of calcium and the calcifying vitamin in the food, or, alternatively, to get all the sunlight possible.

Function of Ligaments

We have seen that man has a skeleton (consisting of two hundred and fourteen bones) which acts as an internal scaffolding upon which are hung, say, three hundred billion cells, allowing fifty billion for the cells of the bones. To tie these bones together there are ligaments, and to move these bones as levers, or to maintain them steady in any desired position, there are the muscles. No skeleton would be any use without active muscles, as can be seen in that rare disease *myasthenia gravis*, or in poisoning with the South American Indian poison *curare*. In such cases the body flops in a helpless heap. The muscles are composed of billions of highly specialized cells

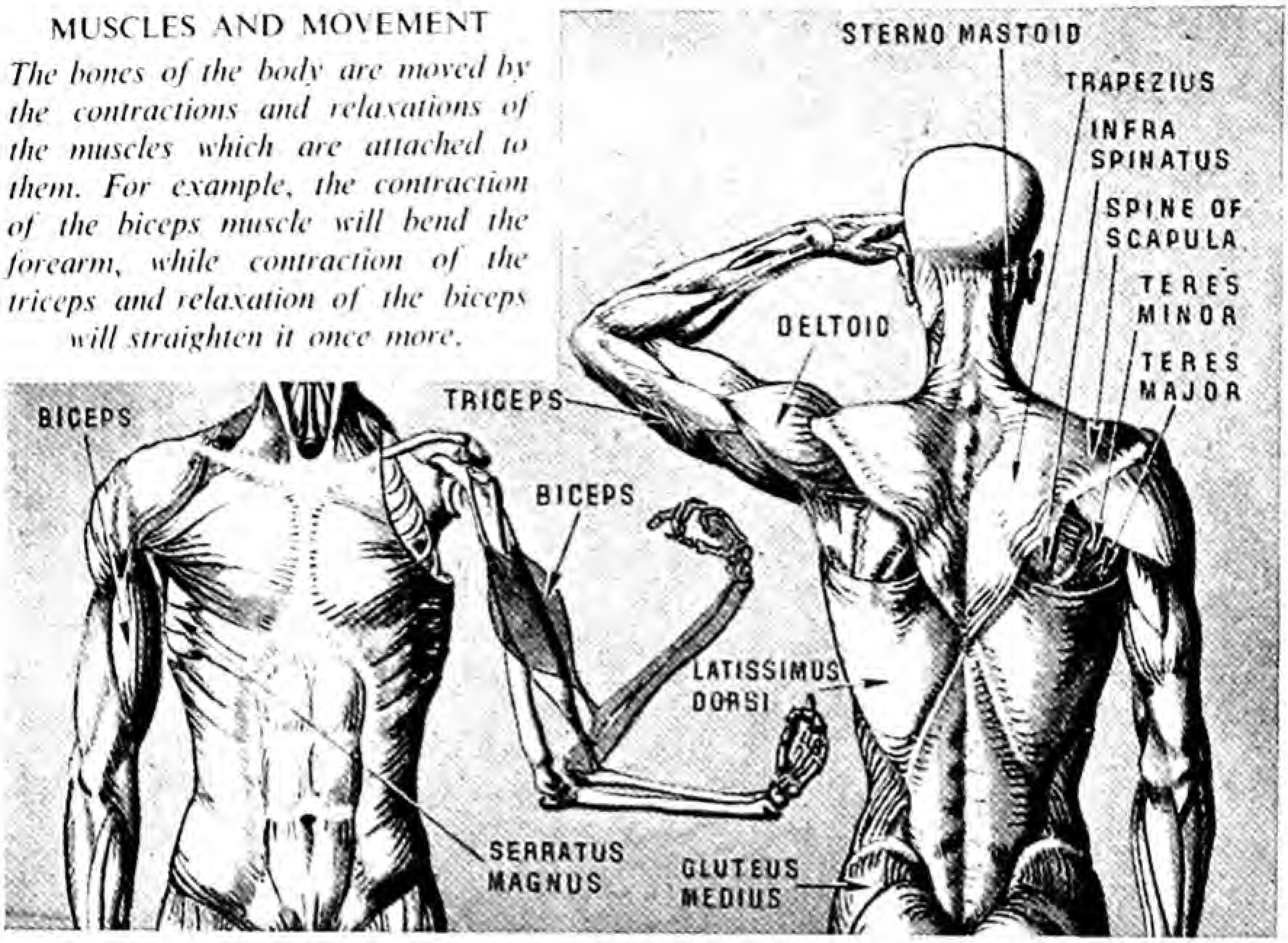


STRUCTURE OF BONE

The hard part of a bone is composed of calcium phosphate and other substances which are laid down in concentric rings round fine blood vessels. The centre of some bones is filled with spongy marrow, soaked in blood, where blood corpuscles are made.

MUSCLES AND MOVEMENT

The bones of the body are moved by the contractions and relaxations of the muscles which are attached to them. For example, the contraction of the biceps muscle will bend the forearm, while contraction of the triceps and relaxation of the biceps will straighten it once more.



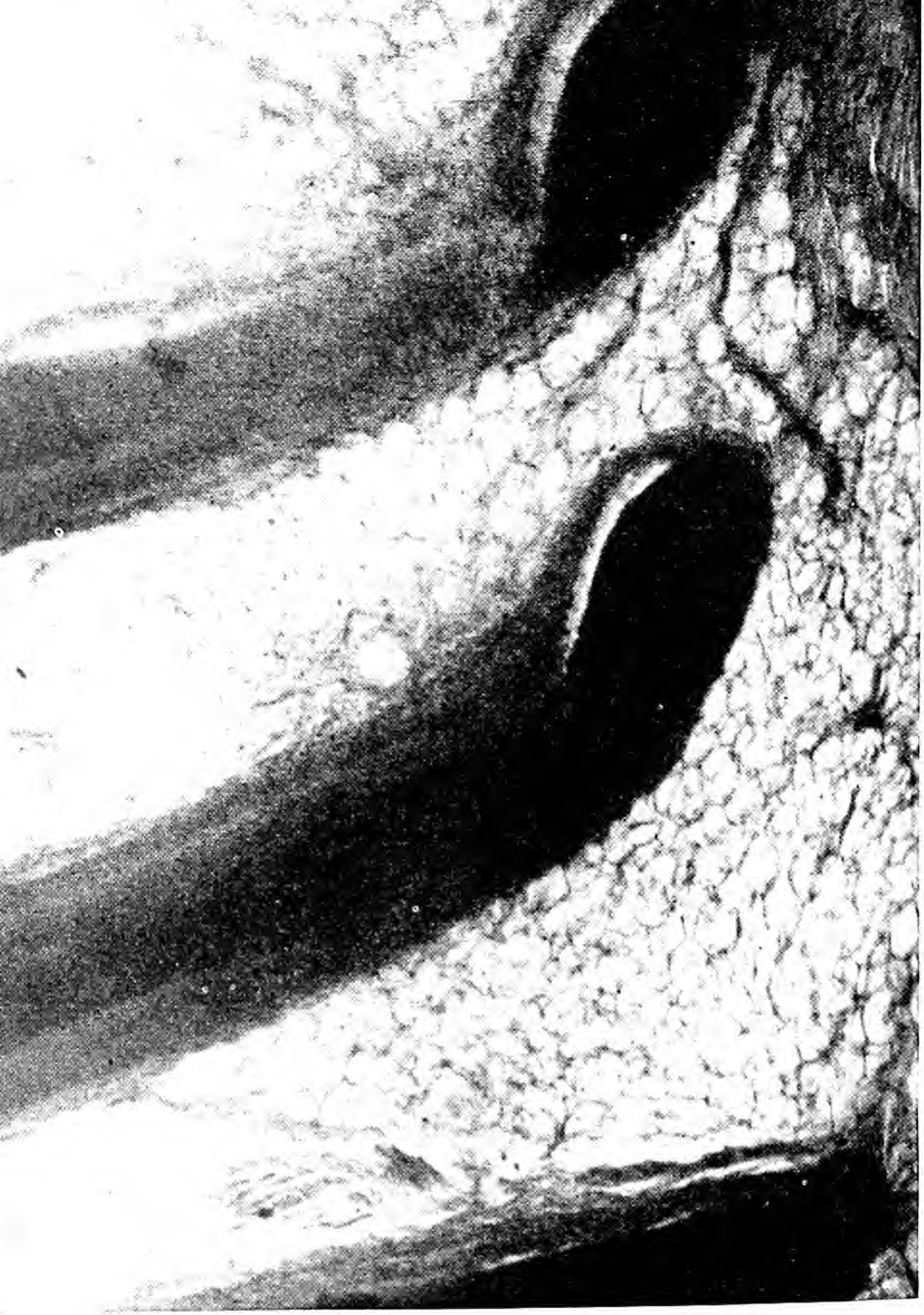
whose function is to shorten at will and produce movements of the bones or to hold them steady in any required given position.

Now, as we have seen in earlier chapters, all living cells, for example, those of the muscles and the bones, must breathe in oxygen and give out carbon dioxide; also they must have materials to consume to produce energy (fats and sugars) and materials to renew their substance when they wear out. In the course of these proceedings, they produce waste substances which must be got rid of, consisting of carbon dioxide, nitrogen-containing bodies, such as urea and uric acid, and phosphates and sulphates.

A simple independent cell, such as a microbe or an amoeba, is in contact with the air or with water containing dissolved air, and it can get its oxygen directly from that air or water, and push waste products out into it. Not so the cells of the body. They live remote from the air. Think of a bone cell buried in the depth of the thigh bone. It has to have oxygen brought to it and its waste products carried away. If either system fails, the cell dies and there is trouble. The bone decays. Similarly with the muscles. Each of the enormous number of muscle cells must have oxygen and get rid of waste products, or the muscle refuses to work and ultimately dies.

Therefore, the body must have a number of systems, or groups of specialized cells to obtain oxygen from the air, to carry that oxygen to the cells, even in the most out-of-the-way part of the body, and to carry away waste products from them. Further, it must have a system, or systems, to get rid of those waste products from the blood. Moreover, it must have a system to prepare from foodstuffs materials suitable for combustion in the cells and to rebuild the body when it is wearing out, or, in the growing young, to enable it to grow.

To obtain oxygen from the air, we have the respiratory system, consisting of nose and mouth, windpipe and lungs. To carry the oxygen from the lungs to the tissues we have the circulatory or transport system, comprising heart, arteries and capillaries. To prepare food for use in the body we have the digestive system, consisting of mouth, gullet, stomach and small and large bowel. To carry the prepared food products to the cells of the body, we have the



HUMAN SKIN AND HAIR ROOTS

A hair is formed of long delicate cells, which are pigmented and horny. Each hair arises from a swelling, the hair root, filled with soft growing cells which replenish the hair material. Two hair roots are shown in the photomicrograph above.

circulatory system again. The waste products of cell activity may be gaseous (carbon dioxide dissolved in tissue fluid) or solid (phosphates, sulphates, urea and uric acid again dissolved in tissue fluid).

To get rid of excess of carbon dioxide the lungs are used. They thus serve a double purpose: intake of oxygen into the blood and output of excess carbon dioxide from the blood. Again, the circulatory system is used to transport the excess carbon dioxide from active tissues to the lungs. To get rid of excess solid waste products, the kidneys have been developed. They take the excess from the blood and pass it into the urine, and to transport this excess from the tissues to the kidney the circulatory system is used.

Finally, all the activities of the body have to be co-ordinated. It is difficult enough in human affairs to co-ordinate the activities of (say), the forty-five million inhabitants of the British Isles. Compare this problem of government with that of managing the three hundred and fifty billion cells which go to make up each human body. Each cell has its task, and its task must be co-ordinated with the task of every other one and work in harmony with it.

Function of the Nervous System

Yet this gigantic problem is solved without any of the friction and maladjustment which often characterize affairs of social government. Strikes are very rare and anarchy just as rare! For this government the nervous system has been evolved, aided by the endocrine (ductless gland) system and the circulatory system. The control government is the brain, acting through a telegraphic system (the nerves) and a postal system (the circulatory system). One thing we have omitted from the highly condensed account of the systems of the body, and that is the way all these systems are tied together, much as the contents of a parcel are held together with brown paper and string. The whole mass of the human body and its cells must be held together, and the naked protoplasm of the cells be protected from the harsh environment.

This is done with connective tissue to tie the parts together, the whole being covered with a rainproof and windproof covering, the skin. The outside layers of the skin are dead, are continually being sloughed off or abraded and have to be as continually renewed from living tissue within. The wants of this tissue, as usual, are supplied by the circulatory system.

How the Circulatory System Works

In all the above, we have mentioned the circulatory system again and again, and it would be well to discuss it in some detail. It consists of a closed system of pipes, containing a fluid called blood, and the heart is a muscular pump which unceasingly keeps the blood flowing round and round from the earliest moments almost of our life in the womb until we die. If the pump stops working for a second or so, we faint, and if for a minute or so, we die. If any part of the system of pipes gets stopped, the organ supplied by that part dies—it mortifies, which is only a way of saying it becomes dead.

Blood is a sticky red fluid containing a large number of little bodies called red and white corpuscles. Roughly half the blood is a pale yellow fluid, called plasma, and half is corpuscles floating round in the fluid. The fluid is sticky because (i) it contains dissolved in it some seven per cent of proteins, and it also carries carbon dioxide, a little oxygen, some chlorides, carbonates, phosphates, urea, uric acid, amino acids, etc., and (ii) it clots, i.e., turns into a viscous jelly, when shed. Blood looks red because of the red blood corpuscles, of which there are nearly three billion in a pint! They are small, disc-shaped cells, very elastic, and red because they have in them a red pigment, called haemoglobin, which has the function of carrying oxygen about the body.

If we have too few red blood corpuscles, or those we have do not contain sufficient haemoglobin, we are weary folk, or in medical language we are anaemic (lacking in blood) and part of the anaemia, so common at one time in women of the working classes, is due to there being too little iron in the diet. For haemoglobin has iron in it, and if a person is not eating enough iron he becomes anaemic. He cannot carry sufficient oxygen from his lungs

to his nervous system and muscles, and so becomes a "weary Willy."

The white corpuscles, much fewer in number (five hundred times less), have the functions of a police system. They arrest and kill off microbes of disease which have crept into the circulation. Further, they can leave the circulation and migrate to a spot where disease germs have got into the system and wall off—put a cordon round—those malignant creatures. The pus of a boil or pimple is a mass of dead bodies of white corpuscles which have died in the defence of the body.

Seventy per cent of the white blood corpuscles, and all the red blood corpuscles, are manufactured in the red marrow found in the interstices of the spongy bone. Anyone can see red marrow in the sawed ends of the bones in ribs of beef. When the conveyor band of our blood cell factory stops, we suffer from pernicious anaemia and we have to take massive doses of liver extract or a vitamin, folic acid, to start it going once again.

Plan of the Heart

Let us look at the heart, the double-barrelled blood pump which keeps the blood and its corpuscles for ever going round and round the closed system of pipes. It is a lumpy looking organ, difficult to make head or tail of at first sight, but a schematized diagram will help. First of all, it is divided into two unequal halves, the right and the left, by a longitudinal septum, and each of these halves is again divided into two parts, one small and one large. We call them auricles and ventricles respectively, but the German name *Vorhof*= entrance hall, gives the best impression of what the auricles are. Veins pour their blood straight and unimpeded into the auricles, but the wide entrances between auricles and ventricles are guarded by valves so that blood can flow from auricle to ventricle, but not in the opposite direction.

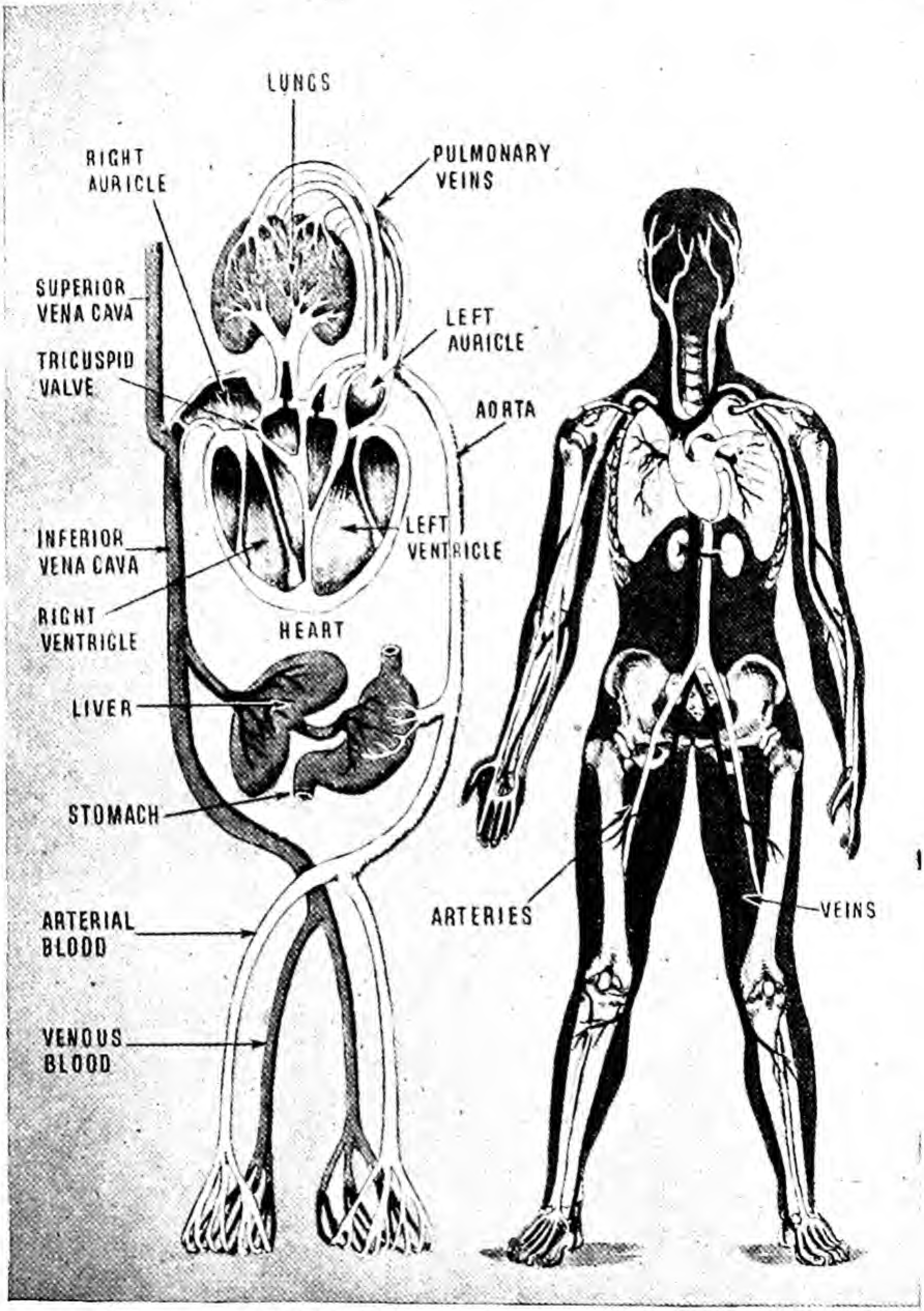
There is a smaller exit from each ventricle; that from the right goes into the artery for the lungs, that from the left goes into the main artery for supplying the body with blood, called the aorta. The entrances to both the artery to the lungs (pulmonary artery) and the aorta are guarded by a circular arrangement of small valves shaped like tobacco pouches. It was Harvey who first pointed out the use of these valves. Those between the auricles and ventricles prevent a back rush of blood from the ventricles, and those at the mouths of the arteries prevent a back rush of blood from the arteries into the ventricles.

Consequently, the blood, if it makes any movement (as we know it does), must pass from right auricle to right ventricle, right ventricle to lungs, left auricle to left ventricle and left ventricle into the aorta. This Harvey deduced and proved by experiment, and it would be a madman who doubted it today.

Contracting Walls

When we say the heart beats, we mean that its muscular walls pull themselves rhythmically together—they contract. And, as the muscle bands are arranged in circular and spiral directions round the cavities, the blood is squeezed from auricles to ventricles and from ventricles to the pulmonary artery and aorta. The two auricles contract almost simultaneously, urging the blood into the ventricles and then about one-tenth of a second later, the ventricles contract (while the auricles become quiescent) and push their contents out into the arteries. Both ventricles contract together (or there is trouble) and remain contracted for about three-tenths of a second. Then the whole heart rests for four-tenths of a second to allow both auricles and ventricles to fill up with blood coming from the veins.

Then the heart beats again, and so on throughout life, accepting blood from the veins and pumping it on into the arteries. If we make any exertion the heart rate quickens—even sitting up in bed will increase the rate of the heart beat, as anyone can verify for himself—and this quickening of the heart beat takes place by cutting down the time the heart rests. (That is why the doctor, when he wants to rest our hearts, puts us to bed and makes us lie flat.) The timing of the heart beat in man can be investigated by a delicate instrument, the electrocardiograph, which records



CIRCULATION OF THE BLOOD

Blood circulates through the arteries and veins shown in the figure above. Blood travels from the heart along arteries and back to it through veins. Arteries and veins are joined by fine capillary vessels which supply the tissues of the body with blood.

the minute electrical impulses given out by the muscles of the heart as they contract.

As the auricles have not much work to do, their muscular coats are not much developed and the electrical impulses given out are small. The right ventricle has less work to do than the left, for it has to pump blood only into the lungs, whereas the left ventricle pumps blood throughout the rest of the body. Compared with those of the left ventricle, the walls of the right ventricle are thin, but not so thin as those of the auricles. The left ventricle has much the thickest walls, for it has the most work to do.

We must now follow the blood on from the heart. From the right ventricle it is forced through the pulmonary artery to the lungs. The pulmonary artery is a relatively thick-walled tube, which can withstand a great deal of pressure, for into its walls elastic and muscular tissue is woven. The distension of these walls squeezes the blood onwards, for it cannot get back into the heart, even when the heart is resting, because of the valves at the mouth of the artery. This artery divides and sub-divides into smaller branches, and ultimately these lose their muscular walls and become membranous vessels called capillaries. These vessels are so small that Harvey could not see them with the magnifying glasses at his disposal. He made a guess that they existed and he guessed right.

Capillaries and Veins

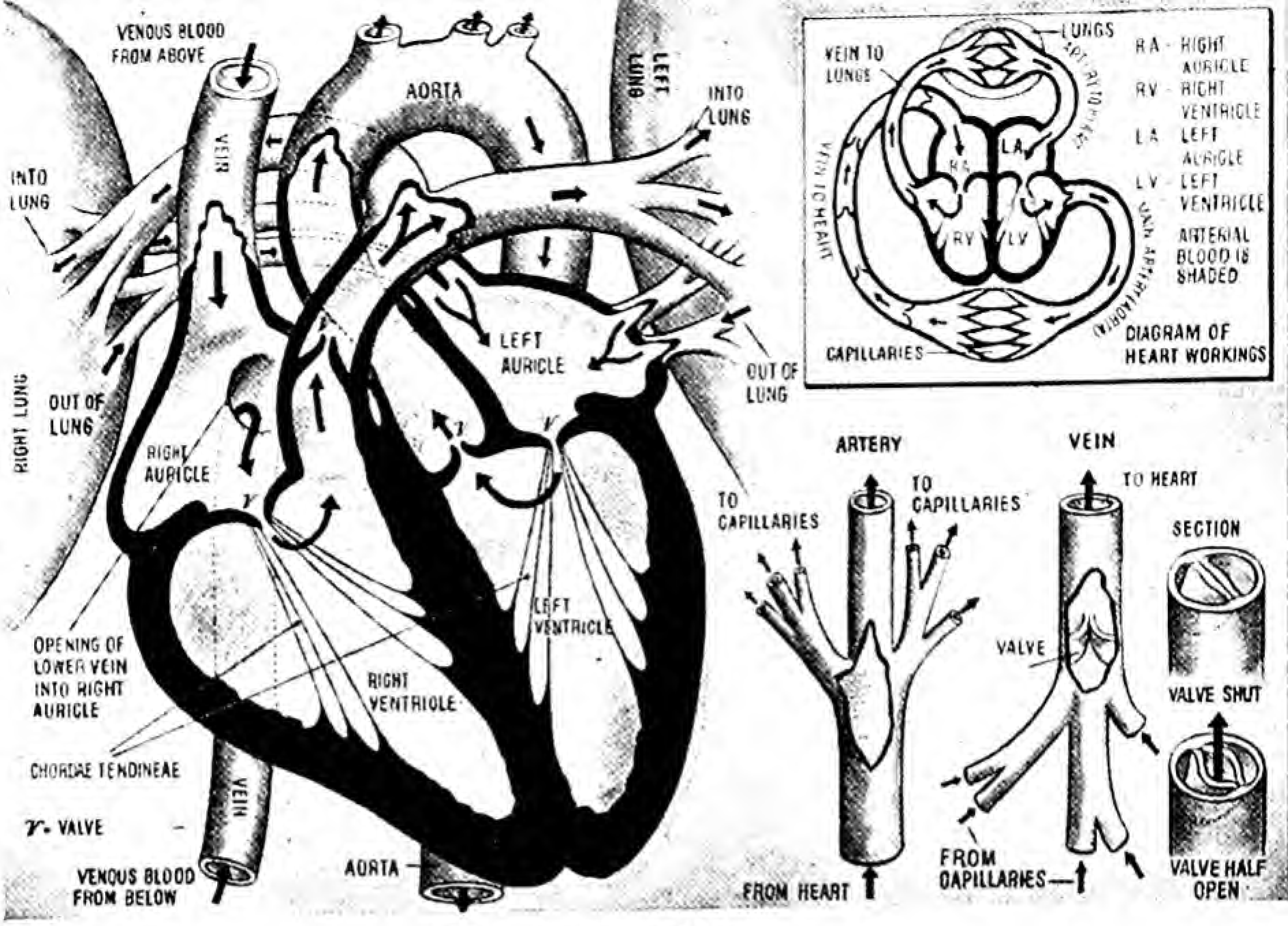
It is through the thin walls of these vessels that carbon dioxide escapes from the blood into the air cells of the lungs and that oxygen passes in the reverse direction. The network of capillaries gives rise to larger vessels, the small veins. These unite into bigger ones and all ultimately join up to form the four veins which pour blood into the left auricle. From the left auricle, as we have seen, the blood flows on into the left ventricle and then is pumped, when the left ventricle contracts, into the aorta. This is a large vessel with an enormous amount of elastic material in its walls, and doubtless each contraction of the left ventricle, forcing blood into it, distends the aorta, as you distend a bicycle tyre inner tube when you wield a bicycle pump. The blood cannot get back into the ventricle when it relaxes, because the aortic valves are shut by the back pressure, so the blood has to go onwards along the aorta (ascending and descending) into the arteries, which are distributed from it to all parts of the body.

The wave of pressure is transmitted along the walls of the arteries, which are thick-walled elastic and muscular pipes and can be felt at various spots in the body as the pulse. One convenient spot is the wrist, where the doctor usually takes the pulse, or on the temples or alongside the wind-pipe. Each beat of the pulse corresponds to a beat of the left ventricle, but is slightly later the farther away the point of taking the pulse is from the heart. Anyone can prove this by putting one finger on the pulse in the neck, which is near the heart, and another on the pulse in the wrist, farther away from the heart.

Dividing Arteries

As in the lungs, the arteries of the body divide into smaller and smaller arteries and finally these open into capillaries which form a network in every organ of the body (the cornea of the eye is an exception). Through the thin walls of these capillaries, oxygen and food materials can pass to the tissues needing them and carbon dioxide and other waste products can pass in the reverse direction. Again these capillaries, as in the lungs, open up into small veins, these veins unite to form larger ones and ultimately all the veins of the head, neck and arms pour into the *superior vena cava* (the upper hollow vein) and those of the trunk and legs pour into the *inferior vena cava* (the lower hollow vein) and these two veins supply the right auricle. The blood, of course, follows these paths and comes back to the place it started from. It has moved, or rather has been moved, in a closed circuit. The least time it takes the blood to get once round the circuit is about thirteen seconds, but, of course, if some of it has to travel a long distance from the heart, for instance, to the skin of the little toe, that circuit must take somewhat longer.

The veins are much larger in cross



BLOOD CIRCULATION

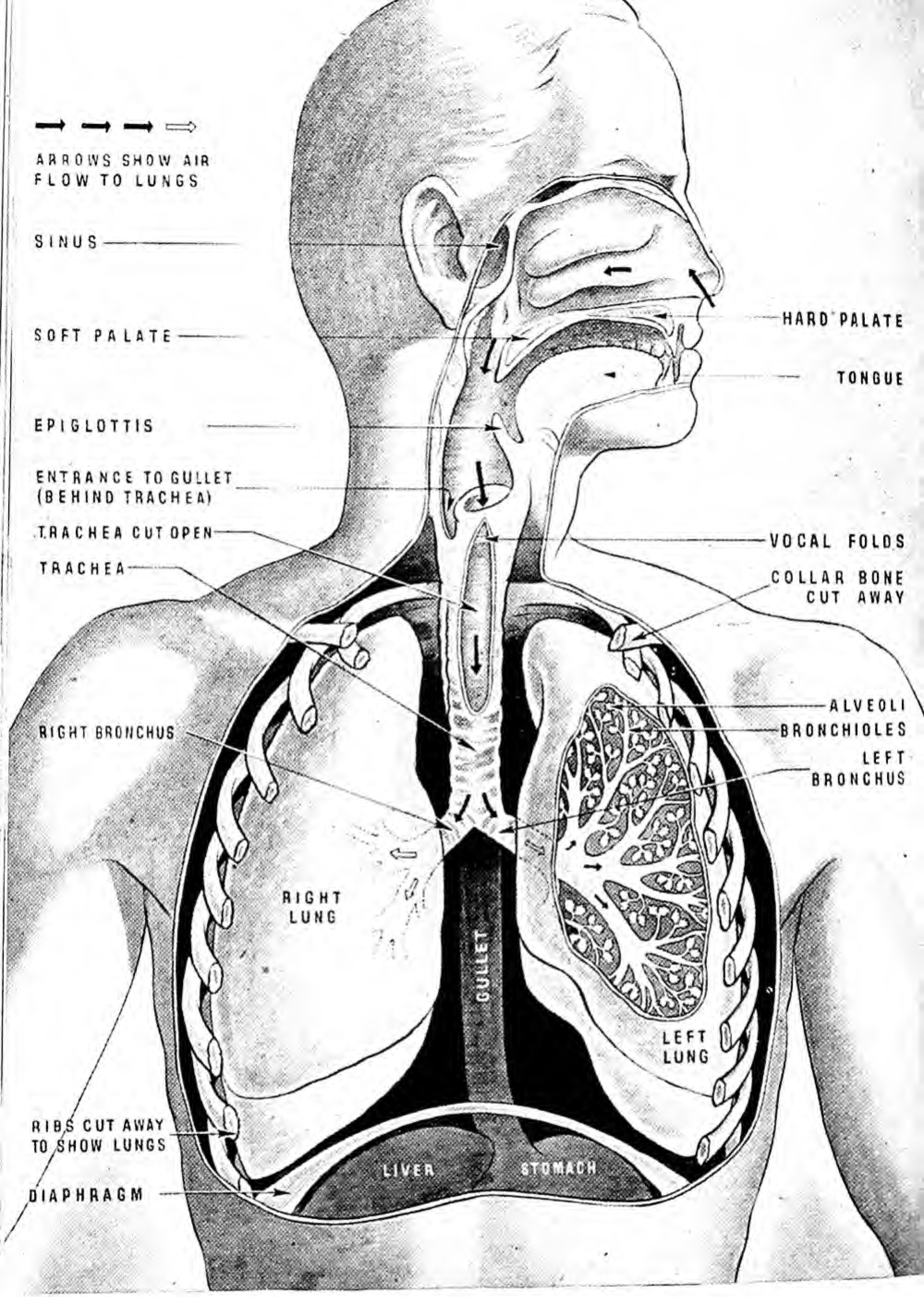
Blood from the rest of the body reaches the heart by the veins shown at the lower left corner of the figure. The arrows show the direction of the circulation through the heart. When the ventricles contract the blood is prevented by valves from passing back into the auricles but must pass out along arteries under fairly considerable pressure.

section than the corresponding arteries and the flow in the veins is more sluggish. Cut an artery and the blood spurts out in rhythmic jets corresponding to the pulse. Cut a vein, and it trickles out. In this circulation of the blood we have an amazing, self-regulating mechanism for carrying to all the living cells of the body what they need in the nature of food and oxygen, and carrying away from them all their waste matter. One mechanism does in the body what, in the life of a household requires ventilating plant, hot-water apparatus, lavatories and a whole fleet of vans and lorries to carry out.

Oxygen has to get into the blood and carbon dioxide out of it. For this, as we have said above, the respiratory system is responsible. Think of the chest as an old-fashioned pair of bellows. Imagine the leather valve in the side of the bellows stopped up. Then every time the handles are pulled apart air would rush in at the nozzle. Every time they are pushed together air would be forced out. The rise and fall of the chest wall in respiration acts like pulling apart and pushing together of the handles of the bellows.

When the chest walls rise air is drawn through nose, mouth and windpipe into the cavity within the chest, mixed with what is there already and then the mixture is pushed out in part as the chest walls fall. Of course, the air does not go into a naked cavity but into the elastic bags which practically fill the true chest cavity and which we call the lungs. Each rise of the chest wall draws air into these bags, and with each fall of the chest wall the bags crumple up and air is forced out again to the outside world.

This action is aided by the diaphragm, a mass of thin muscle and tendon which divides off the chest cavity from that of the belly, or abdomen. This dome-shaped muscle flattens when it contracts, thus increasing the volume of the chest cavity, and so draws air into the lungs. Both processes are at work in most people, but men breathe more by use of the diaphragm and women by raising the chest wall. Tenors and basses can sing in starched shirts,



AIR PASSAGES AND LUNGS

When we inhale, air is taken in through the nostrils and passes along the trachea to the alveoli where the exchange of oxygen and carbon dioxide from the blood takes place. The lungs are expanded by the combined action of the ribs and the diaphragm

trebles and altos prefer their chests to be free.

Over the surface of the small air cells of the lungs, which consist of a very thin membrane, run the capillary blood vessels of the lungs, so that oxygen of the air in the lungs is separated from the blood only by two very thin membranes and a film of moisture. Consequently, it can easily make its way into the blood stream and unite with the red pigment haemoglobin in the red corpuscles. When doing this, it turns the pigment from a dark crimson to a vivid scarlet. Blood running to the lungs is dark. That coming away from them is bright red. At the same time that oxygen passes into the blood, carbon dioxide escapes from it into the air in the lungs and as the bellows of the chest collapse some of this carbon dioxide is pushed out through the windpipe and nose into the external air.

Control of Respiration

Air, the ordinary atmospheric air, has about twenty per cent of oxygen in it and next to no carbon dioxide (0.04 per cent). Air coming back from the lungs has only about fifteen per cent of oxygen and as much as four per cent carbon dioxide. It is the pressure of carbon dioxide in the blood which determines the rate at which we breathe. When we take exercise our muscles make extra carbon dioxide; this increases the pressure of carbon dioxide in the blood and this increased pressure stimulates the part of the central nervous system which governs respiration to work faster and to make us breathe more deeply. Not only does this get rid of the excess carbon dioxide, but it gives the oxygen more chance to push its way into the blood —a simple and highly efficient method which, at one and the same time, helps our muscles to get rid of the waste carbon dioxide and to obtain the extra oxygen that they require.

As we have said, the cells of the body need food and need it all the time. Now, it would never do to put food straight into the blood. Much that we eat will not dissolve in water and even if it were dissolved in water the cells could not make use of it. In fact, if the white of egg gets into the blood it acts like a poison! Worse still, another person's blood is not necessarily tolerated. At times it is essential to pump human blood into a person who has lost a lot of blood, but the surgeon has to be careful to see that the particular kind of blood supplied is compatible to the patient. There are five types of blood at least (one is fortunately very rare). Some of us (universal donors) can give blood to anybody, but others can give to one type only. Otherwise, the red corpuscles of the poor recipient run together and become useless. In fact, the wrong blood would probably kill him—a truth that might well be used by writers of "thrillers."

All blood when shed clots; if it did not, a mere scratch would make a person bleed to death. The clotted blood plugs the wound until the repair mechanism gets to work and the damage is remedied. For this clotting, the blood keeps in reserve materials which, when they come into contact with damaged tissues, turn into a ferment which makes blood clot. Some people are born without this mechanism and their life is a misery. The late Czarevitch of Russia was one, and sundry other male grandchildren or great grandchildren of Queen Victoria were, or are, in the same plight. This trouble, called haemophilia, is handed on by women to their offspring, and it appears only in the males. Disturbance of the clotting mechanism is also caused by lack of a particular vitamin (K), but luckily this vitamin can be given through the mouth or be injected and so restores the power of clotting.

Digestion

After this digression, which illustrates the subtleties of control essential in the human body, we can return to digestion. Even cane sugar, which is soluble enough in water, has to be digested to two simple sugars (grape sugar and fruit sugar) before it is any use. So we and all animals have had to employ a digestive system to break down the component parts of our meals into something which the cells of our bodies can use. And each digestive system is appropriate to the food eaten. Cows, horses and rabbits, which eat grass, have

digestive systems unlike ours. Cows have four stomachs, we have one. Horses and rabbits have a tremendous caecum (or blind bowel), ours is quite small, man's alimentary tract consists of mouth, gullet, stomach, small and large intestine. The mouth chews the food and the gullet acts as transport tube to the stomach, where a small amount of digestion takes place.

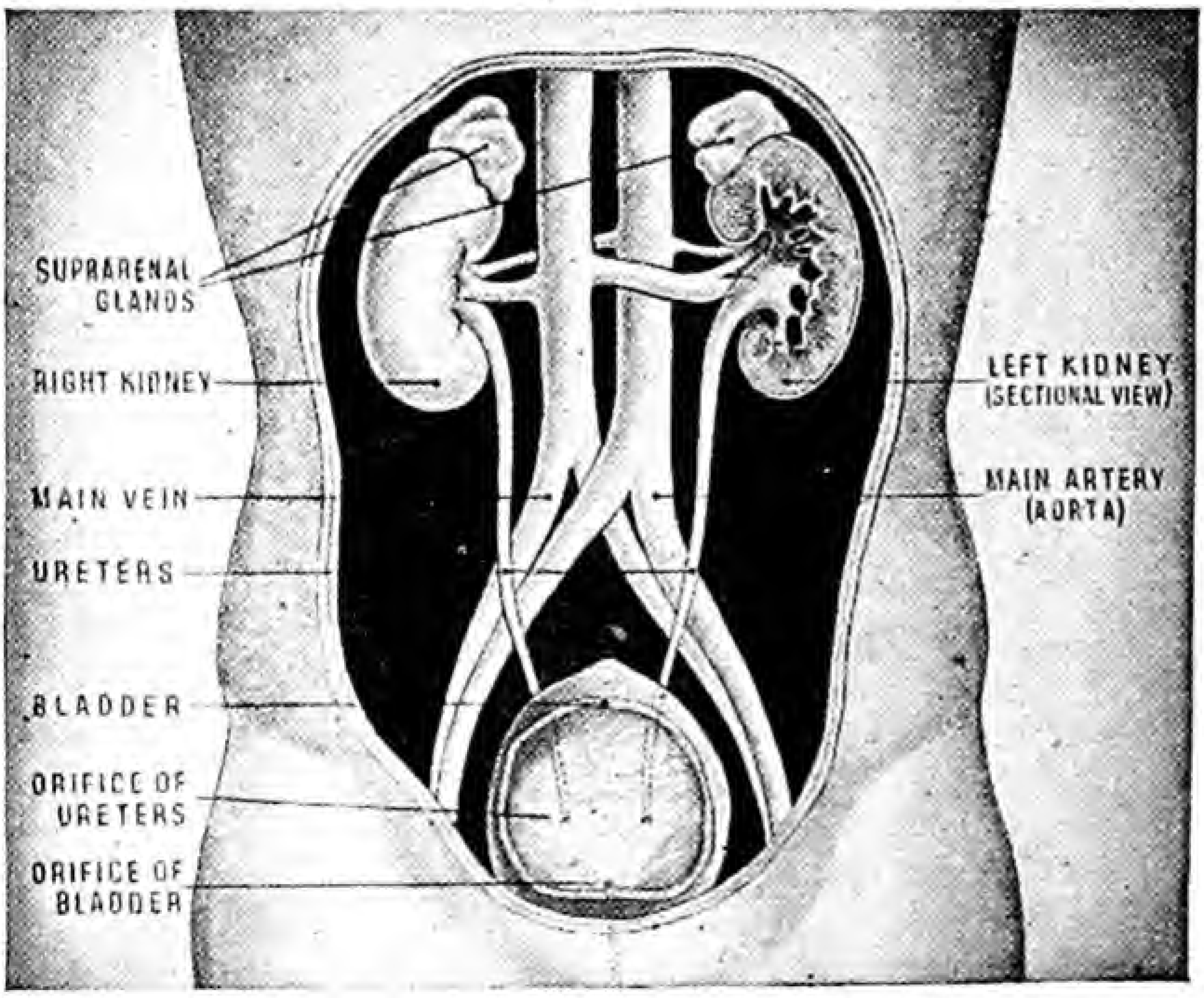
Almost the whole of digestion and absorption into the blood of food material takes place in the small intestine. Anything undigested or unabsorbed passes into the large intestine, where any remaining traces of nutriment are absorbed with the water in which they are dissolved. The resulting concentrated debris is collected in the lower end of the large intestine until it is essential to pass it out through the rectum to the outside world.

Work of Ferments

Ferments are essential to digestion, which is a process of tearing the complex food materials into much simpler substances. Starch in the food (bread, biscuits, pastry, etc.) has to be changed to grape sugar. The body cannot do this at one fell swoop. There is a ferment, ptyalin, in the saliva, which converts some of the starch to malt sugar; a ferment is secreted by the pancreas and completes this process, and a ferment called maltase, secreted by the small intestine, finishes the transformation to grape sugar. In this form, the grape sugar is absorbed into the blood stream, mainly in the small intestine, but also to a lesser extent in the large.

For the digestion of proteins, a more complicated process is essential. The basis of all living matter is protein. There are millions of different proteins. Egg white is a good example of a protein, though one must say at once that there are at least four different proteins in it. Meat is largely a mixture of proteins. Flour contains from eight to fourteen per cent of proteins. Proteins are alike in being made up of twenty-two different units called amino acids, and their differences are accounted for by the way these amino acids are strung together. It is helpful to think of proteins as necklaces. You can make a necklace of pearls, diamonds, glass beads, wooden beads, shells or plastics, or you can mix these; you can make many more varieties of necklaces if you mix them. Proteins are long chains of amino acids, and their differences are due to the number, kind, proportion and arrangement of the different units.

Now, the body does not want proteins as such, but as the individual units of which they are composed. So it tears these



KIDNEYS AND GLANDS

The kidneys are shown here in relation to the blood vessels which supply them and the bladder, into which the ureters pour their urine. Although the suprarenal glands are placed so close to the kidneys, they are not related to them functionally, but are glands of internal secretion or endocrine organs. The suprarenal glands secrete a substance called adrenalin.

long chains to bits until there is nothing left but amino acids. It then absorbs them, uses the ones it wants to build up human protein and throws the ones it does not want on the bonfires of the human body. To build human proteins, animal proteins such as those of cheese, eggs, fish, meat and milk are better than plant proteins (for example, those of flour, peas, beans and potatoes). This is why children, pregnant women and convalescents need more animal proteins in proportion to an ordinary healthy adult.

Digestion of Proteins

The digestion of proteins starts in the stomach. The long chains are there split into two or three smaller proteins under the influences of a ferment called pepsin, secreted by the walls of the stomach. In the small intestine these proteins, or any undigested protein, meet a ferment, trypsin, secreted by the pancreas. This carries on the process, breaking down the proteins to still smaller portions. Finally, another ferment, erepsin, secreted by the walls of the intestine, finishes the work, and the protein is now completely broken down into amino acids and absorbed into the blood stream in that form from the small intestine.

It is still not quite certain how the body treats the fatty substances of the food. They are broken up into tiny droplets (an emulsion) in the small intestine. Some of these droplets are broken down by a ferment, steapsin, secreted by the pancreas, into glycerine and fatty acids and absorbed as such. But whether all are broken down is not certain. It is possible that the small intestine absorbs some of these droplets as such without changing them chemically. For the emulsification of fat, bile (secreted by the liver) is essential, so when insufficient bile is getting into the small intestine, as in jaundice, fats are not digested, and should be withheld.

The material expelled at the far end of the alimentary tract, faeces, consists of: (i) indigestible material (such as bran, plant fibres and so on), (ii) digested but unabsorbed material, changed somewhat by the action of microbes, (iii) digestive juices and mucus, and (iv) microbes, living and dead. There is no evidence that the ordinary person is poisoned by his large bowel or that constipation is dangerous, though uncomfortable. There is evidence that the use of purgatives upsets absorption in the small intestine and alters the nature of the microbes in the large intestine. These microbes manufacture vitamins of class B and also vitamin K and thus man obtains some of these necessary substances. The large intestine is no death trap, but an essential part of the body's economy.

Man's food comprises the following chemical substances: proteins, fats, carbohydrates (starches, dextrins and sugars); mineral elements (some dozen necessary elements); indigestible material, often called roughage; flavouring materials; vitamins and water. To obtain these, man must take a mixed diet of animal material—vegetables, fruits, and cereal products. The only thing he need really worry about is to get plenty of dairy products, greengroceries and fat fish (herrings, sprats or salmon), and if he does this, but otherwise eats the usual foods, he can be certain that he is obtaining all he requires. There is little need for taking thought of what and how he shall eat except about meal times and the number of meals.

Suitable Meals

It has fairly conclusively been proved that three main meals, breakfast, lunch and supper, with two smaller meals at mid-morning and teatime, form the best arrangement of meals for the ordinary person. If possible these small extra meals should include some fruit, salad or milk. It is advisable to avoid special diets except under doctor's orders.

So far, we have seen the food material into the blood only. This is a closed circuit and the blood never gets directly into contact with the tissues. Therefore, these food materials must leak out of the blood into the fluid (tissue fluid) which surrounds the tissues. This fluid we often see when we graze the skin but not deeply enough to draw blood. The simple sugars and the amino acids easily pass through the thin walls of the capillaries into the tissue fluid,

but quite how the fat does the same thing is not easy to understand. We know that it does, or the body would never absorb fat.

The tissue fluid is kept from stagnating partly by movements of the body (which produce a natural massage of the tissues) and partly by flow into the lymphatic system. This is a system of vessels, rather like capillaries, starting in the lymphatic spaces between the tissues and emptying into larger and still larger vessels which run towards the great veins entering the heart. The lymph channels of the head, neck and right arm pour into the right subclavian vein (just under the collar bone) and those from the left arm, legs and trunk pass into the left subclavian vein. Not only does this system help to drain the tissue fluid and keep it moving, but it carries along with it white corpuscles manufactured in the lymph glands. These glands act as filters to prevent microbes passing into the blood.

Need for Food

It is time to turn to what the tissues do with the food substances brought to them via the blood and tissue fluid. They need food material for two purposes: (i) to build up and replace wear and tear of the tissues, and (ii) to provide them with fuel material as a source of energy. The first requirement is supplied mainly by the amino acids, and the second by fats and sugar. How "Whatever Miss T. eats, turns into Miss T." is one of those mysteries which we shall probably never unravel. We know that the tissues seize the circulating amino acids and build them up into Miss T., or into a Winston Churchill or into you and me, as the case may be. Although all our tissues are in a violent state of change, none the less they look much the same, at any rate from the time we reach adult stature until we pass middle age. Even then, their configuration is recognizable until we die.

The tissues, even those of the bones, are continually receiving material and as continually shedding waste products. The solid waste materials are mainly ammonium salts, purine bodies, phosphates and sulphates. These are dissolved in the tissue fluid, pass out into the blood, and the ammonium salts are changed by the liver into urea, and the purines into uric acid—in man, the apes and the Dalmatian dog—but into allantoin in other mammals. Birds and reptiles turn both ammonium salts and purines into uric acid.

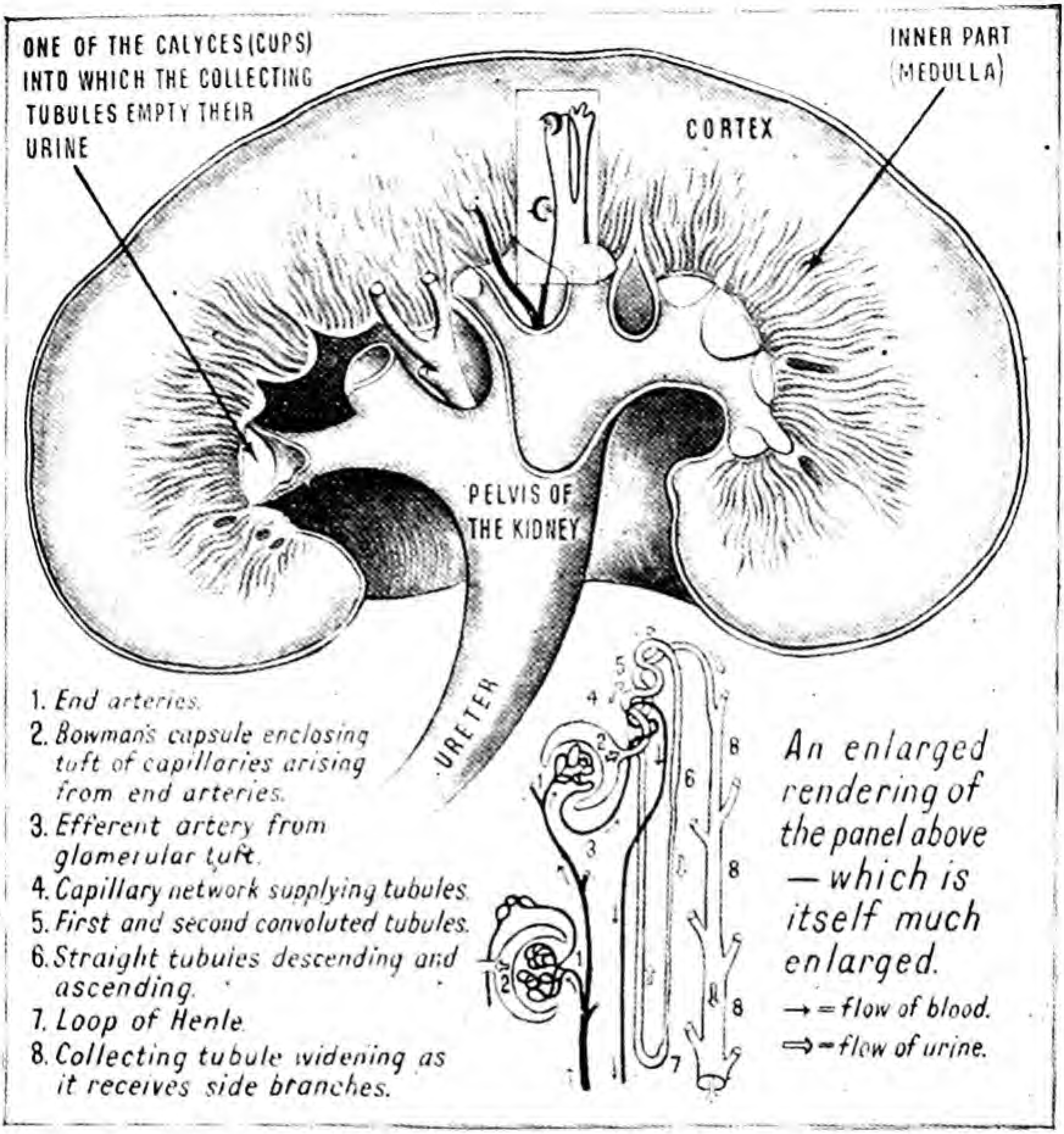
If these waste products are not ejected from the blood tissue there is trouble. In gout, the uric acid is laid down in the joints, instead of being got rid of. Normally it, and the urea, phosphate and sulphates, are got rid of by the kidneys, and as is well known, if the kidneys do not do their work properly the body dies.

Blood Supply to Kidneys

The kidneys are two bean-shaped organs situated somewhat high in the back, with an extraordinary blood supply. The illustration gives an idea of the relation of the blood vessels to a set of complicated tubules in the kidney. Fluid is filtered off at the tufts of capillaries called the glomeruli and passes down them into cup-like spaces (calyces) at their far end. In its passage, it is changed from blood filtrate into urine. Some water is abstracted and possibly sugar and other things. Whether urea and uric acid are secreted by the tubules into the urine is not definitely known. Anyhow the excess of urea, uric acid, phosphates and sulphates of the blood is found dissolved in the urine, and passes from the calyces of the kidneys into the ureters and is stored in the bladder until it is convenient to empty that organ.

When fats and carbohydrates are burnt in the air they give rise to carbon dioxide and water. Exactly the same happens in the body. The products pass into the tissue fluid and thence into the blood. The excess carbon dioxide, as we have seen above, is removed by the lungs. Excess water is removed in three ways: (i) by the kidneys in the urine, (ii) by perspiration through the skin, and (iii) in the moist breath. Weather, and the amount of exercise taken, determine the paths of excretion of excess water.

The amount of water we drink is important. It must be recognized that each one of us has at least sixty per cent of



REMOVAL OF BODY WASTE

The kidneys remove the waste by-products of the body's activity. Blood vessels carry these waste materials, dissolved in blood, to the kidneys. Here the blood vessels break up into the finer capillary vessels which enter the little Bowman's capsules where the waste products are gathered and finally poured into the ureters.

water in him as a whole. Further, it is in this water in the tissues that all the chemical processes which characterize life go on. No water, no life! As the body is continually losing water in the breath, perspiration and urine, this water must be continually replaced. Without drink, we die in a few days. We produce water by burning fats and carbohydrates in the body, but this is not enough to cover our losses, so we drink. The deficit in quite ordinary weather and in sedentary life is about two pints per day, and that is the least we should drink. In hot weather, dry climates and when taking exercise we need more.

Fortunately for most of us, the regulation is automatic, for if our tissues are getting dry, our saliva dries up at once, so that the throat gets dry and we feel thirsty. But the regulation is not entirely automatic. Some people acquire fixed habits about drinking but only drink a definite regulated amount at each meal. If such people move into a dry climate, say North America in winter,

or into steam-heated buildings, and carry on with their customary routine, they may lose weight and feel miserable.

When taking exercise it is right to drink frequently, but it must be realized that drinking on a completely empty stomach paradoxically makes us thirstier than before, for a sudden douching of the tissues with water sets the kidneys actively to work and the body loses more water than it gains. This is a warning to cyclists and hikers in hot weather. For ordinary purposes two pints a day is the minimum and there is no reason for taking more than two quarts. When exercise is taken in very hot weather, it is well to take slightly salted water (a teaspoonful to a pint) because the body loses salt in the perspiration. Otherwise, the muscles get cramp (miner's cramp) and later the body collapses. This type of collapse was encountered in North Africa and other warm spots during the war of 1939-45, and was treated by giving large amounts of salt—up to two ounces per day.

Regulating the Body Cells

In all the foregoing pages, it has been insisted that the body is self-regulating. It consists of three hundred and fifty billion cells. Now, it is difficult to manage the two thousand million people who inhabit the earth. In fact, we are making a poor show of that, but the body of each one of us has to manage eighteen thousand times as many units (cells) as there are people in the world, and, on the whole, it manages this task pretty well. Remember that each one of these cells is a potential anarchist. There is throughout life a competition between them for oxygen and foodstuffs, and those warring wants have to be adjusted for the good of the whole body. "To each according to its needs, from each according to its ability" is the communistic rule of the body. In digestion, the alimentary tract wants extra blood. It gets it. When doing mental work, the brain needs more blood. It gets it. When taking exercise, the muscles need more blood. They get it. How is this complicated control managed?

There are two factors by which the body is made to act as a unity, that is to say, is integrated or made into a whole: (i) the endocrine organs (pituitary gland, thryoid gland, suprarenal gland, etc.), and (ii) the nervous system. The endocrine organs are used for controlling things about which there is no particular hurry, such as the rate of growth of the bones or the rate at which tissues produce heat; but the nervous system is used to bring about actions which need considerable hurry, for instance, when a brickbat is seen to be approaching the head or one treads on a pin.

The endocrine organs post chemical messengers into the bloodstream to distant tissues to get on with the job, much as the Treasury's myrmidons post income-tax demands. A day less or more does not matter much. But the nervous system works more like the telephone. If a house is on fire, minutes matter, so one telephones for the fire engine. Now, in the body fractions of a second matter, and the body can send messages to the central nervous system, which can decide what to do, and telegraph instructions to the appropriate muscles in as little as four twenty-fifths of a second!

Reference has been made to nervous systems and to reflexes, the unit activities, upon which the functions of the nervous system are based, in earlier chapters, so further development of these subjects is unnecessary. But the endocrine organs need a few words. Throughout chemistry we come across substances which hasten a reaction which otherwise would be slow. Just a trace of water vapour is necessary to cause a mixture of coal gas and air to explode when ignited. (Explosions are usually combustions in a hurry.) Such substances are called catalysts. Water vapour catalyses the burning of coal gas. Now the body, in the thousand and one chemical reactions necessary to life has to use catalysts.

Home-made Catalysts

Some of these catalysts are home-made in the endocrine organs. We call them hormones. The thyroid gland manufactures a hormone, thyroxine, which catalyses the rate at which tissues consume sugar. If the thyroid does not make enough, the

person suffers from always feeling cold. If too much, he has to live in a perpetual draught because he is too warm. Also, to enable the body to store sugar, the pancreas makes insulin and secretes it into the blood. If it makes too little, a disease known as sugar diabetes develops. If too much, it produces hypoglycaemia, or too little sugar in the blood, and extremely unpleasant life is in either case. And so on, through the whole range of the endocrine organs—which need a volume to themselves.

Other home-made catalysts are the ferments, which we have met in discussing digestion. But there are many catalysts which are not home made. They have to be taken in with the food. Some are simple, such as iron and lime; but many of them are more complicated, so complicated and elusive that the organic chemist finds difficulty in manufacturing them in the laboratory, though he can and does make them.

These food catalysts or food hormones, we call vitamins. Much has been heard about vitamins ever since 1912 when they were first christened; they had been discovered earlier. And intermixed with the extremely good work done on them has been no end of rubbish. They, too, need a whole book to themselves. Doubtless vitamins are essential to life and well-being, but the general reader is advised not to attach exaggerated importance to them. If he eats a normal, well-balanced diet, he will probably get all the vitamins that are necessary for perfect health.

Test Yourself

1. Why is the skeleton an essential part of the body and what functions does it perform?
2. What are the functions of bone and gristle (cartilage) respectively?
3. How does a cell buried deep in the body obtain food and oxygen?
4. What are the functions of the blood, the heart and the arteries and veins?
5. How is food prepared for use in the body after it has been eaten, and how is it transported where it is needed?
6. How is the human body integrated?

Answers will be found at the end of the book.

ABORIGINES MAKING FIRE

Man's ability to make fire helps to prove the superiority of his intelligence over that of animals. To produce combustion requires reasoning, the power to see relationships as well as some mechanical skill, and no animal has yet been found which could imitate man in this activity. Thus the primitive savage is superior to the most highly trained animal.

CHAPTER IX

INTELLECTUAL MAN

MAN is distinguished from the rest of the animal kingdom in many ways. He is a fire-making animal, a laughing animal, a speaking, reading and writing animal. He makes and uses tools. He foresees his material needs and cultivates and stores crops. Man's mind can wander through space and time; the animal is limited to the here and now.

Some of the activities mentioned as distinctively human are seen in the animal kingdom, but only in a very rudimentary degree. Some animals, for example, store food, while ants and termites actually cultivate fungus for food. Bees, by a kind of cultivation, produce different types of bee. The queen bee, for instance, is raised from an ordinary grub specially fed.

Some writers have claimed that animals speak. They quote the old rhyme: "Why language, then, to man confined? A dog can say what's in his mind." But it is a misuse of words to call speech the few instinctive cries of the animals and birds, or the imitative sounds of the parrot.

Man's distinctiveness is most marked in his intellectual, moral and religious life. It has been argued that the difference between the mental powers of man and of the animals is only one of degree; that there is less difference between a savage and an ape than between a savage and a fully civilized man. This argument is unsound, and the difference between man and the animal is so great as to become a difference in kind.

If a six-months-old infant from a savage tribe is placed in an educated home, and given all the educational opportunities of a Western boy, in twenty years the gulf between savage and civilized man will have been bridged, and the adult savage will be at much the same stage of mental development as the young Westerner. But if, on the other hand, a chimpanzee baby is placed in a similar Western home, he will be incapable of taking advantage of his intellectual environment and after twenty years will have progressed little. One of his major disadvantages will be his complete inability to learn to speak, to read or to write.

The difference between the mental calibre of man and of the animals is illustrated by our use of the word intellectual. We talk of an intellectual man but not of an intellectual animal. An intelligent dog, yes; but the warmest dog-lover will not call his faithful friend intellectual.

Man's intellect involves mental organization, knowledge, judgment, reasoning, powers of memory, all of which far transcend the mental life of animals.

Man's thoughts can range the past, present and future, and can traverse boundless space; but the animal's mental life is limited to the present time, and to the immediate surroundings.

There is thus a great gulf fixed between the intelligence of an animal and the intellect of man; and when we consider the moral and religious life the words have no meaning as applied to animals.

What is Intelligence?

Before further considering man's superiority in intelligence, we should ask what is meant by intelligence.

An intelligent person is mentally alert; he is not floored as often as duller people are by an unexpected situation; but he finds a way of dealing with it.

A person of quite moderate intelligence can become skilled in dealing with a complicated problem if he repeats it often enough; but a person of high intelligence sees the solution to new problems.

Poor intelligence wastes time on matters unrelated to the main issue; it "cannot see the wood for the trees." High grade intelligence, on the other hand, quickly brushes aside irrelevancies and reaches the heart of a problem.

The patients in a certain mental hospital were placed in a bathroom where the taps were full on, and the bath overflowing;

each patient was asked to empty the bath by baling out with a vessel provided for the purpose. If he did not first turn off the water taps, his omission was regarded as an indication of very low intelligence.

This is a homely example, but the problem it illustrates differs only in degree from the problems of everyday life, and also from the really complex problems with which our intelligence is confronted.

How does intelligence work, then? When a mechanic diagnoses the cause of a car breakdown; or a doctor a disease; when a judge decides the principle to be applied in his judgment; when a scientist strives to solve the elusive problems of nature; or when a chimpanzee sees that a stick of required length can be made by joining two shorter sticks, what is the essential quality of the intelligence which discovers the required solution?

Grasping Relationships

This essential quality, to express the matter simply, is shown by the quickness and accuracy with which we see the relationships in a situation, and apply those relationships. The patient in our bathroom example, who did not first turn off the taps which were pouring water into the bath, failed to see a very important relationship between the water coming in, and the water flowing out; he had a very poor endowment of this commonsense, this seeing of relations.

In recent years, a technique of intelligence testing has been devised, and the questions used in such tests are based on the principle we have mentioned. Thus, to give a very simple example, a child may be asked to complete with a fitting word the statement "as foot is to shoe so is hand to ——?" By use of intelligence, the relationship foot and shoe is seen and this relation as applied to hand and glove is educed, or drawn out.

Older students might be asked to comment on the old story of the man who fell asleep in church. During his nap, he dreamed he was in Paris at the time of the French Revolution, was sentenced to be guillotined and was on the scaffold awaiting the descent of the fatal knife. At this point in his dream his wife, who was seated beside him in the pew, noticed him nodding and tapped him on the neck with her fan. He fell dead in the pew.

Some hearing this story for the first time will see, and some will not see the essential point, that it is impossible; as if the man fell dead he would have been unable to recount his dream.

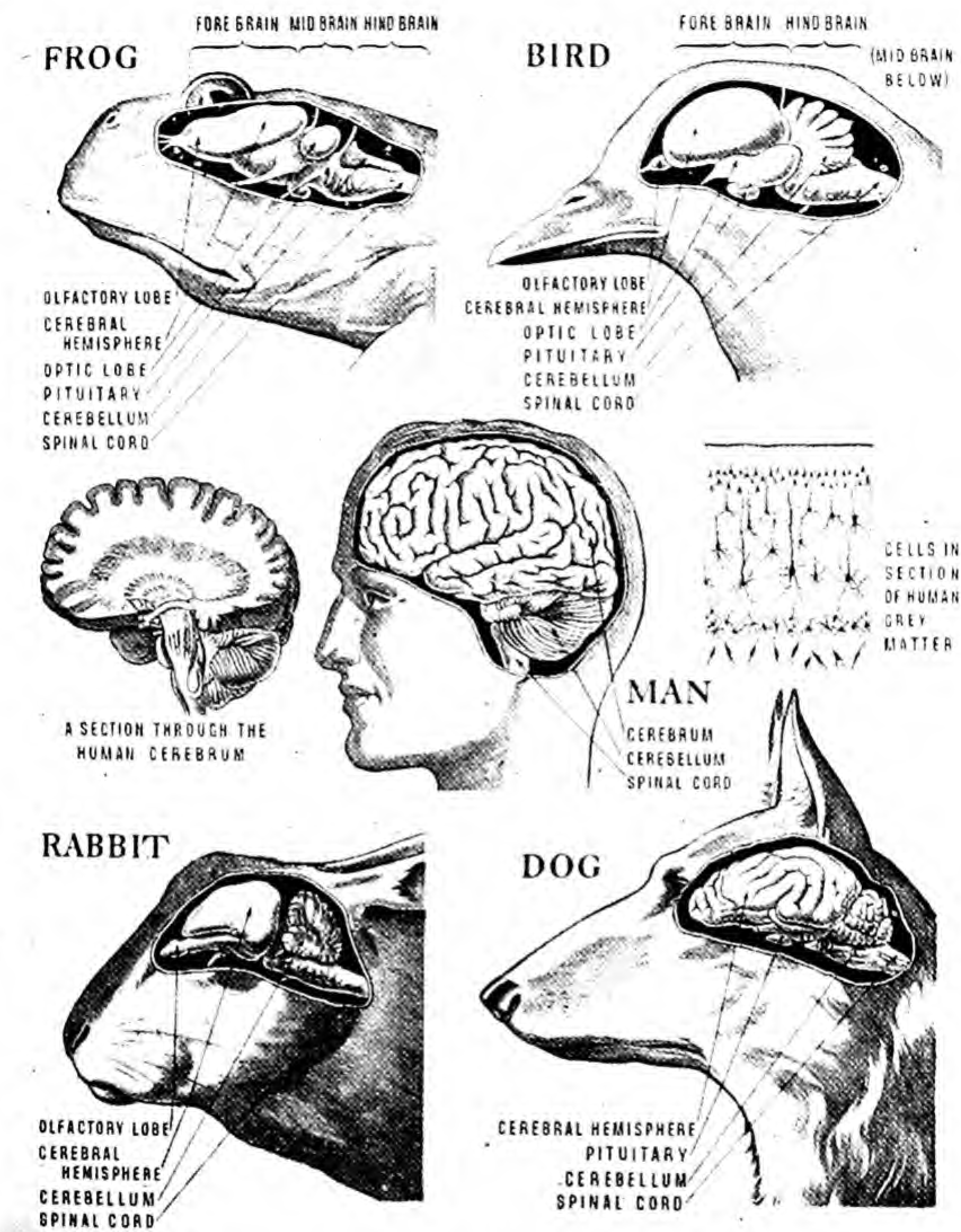
Two Governing Factors

Intelligent behaviour depends upon two factors. The first is a general factor, called general mental ability or "*g*" for short. This is inherited. If we have a high endowment of "*g*," let us not boast about it. We did not acquire it through our own efforts or merit. We are no more entitled to credit for it than we are for the colour of our eyes. Similarly, a man is not to be blamed if he has moderate or low intelligence. We are, however, to be commended, or blamed, for our use or misuse of our intelligence.

The second factor in intelligence is a specific one, and is largely acquired. It has been described as a specific mental "engine" peculiar to an ability—say ability in languages, music or art.

Dr. Johnson must have been thinking of general mental ability when in his forthright way he exclaimed, in reply to a suggestion that men possess various intellectual qualities such as great learning, good judgment, vivid imagination and so forth: "No, sir, it is only that one man has more mind than another. He may direct it differently, he may by accident desire to excel in this study or in that. Sir, the man who has vigour may walk to the east just as well as to the west." The learned doctor went on to suggest that Sir Isaac Newton could have so directed his great mental ability as to write great poetry.

We may venture to doubt this last assertion, but "*g*," general mental ability, certainly operates in all our mental processes. Some abilities, say in mathematics, depend almost entirely on the inherited general ability, and any acquired skill in these subjects is only of subsidiary importance. Mechanical skills, drawing and the like, depend as much, or more, on



BRAIN AND BEHAVIOUR

Some regions of the brain are concerned with the senses and bodily activity, others with planning, knowing and understanding. But the cerebrum also acts as a whole, e.g. in learning and remembering. The cerebrum is a co-ordinating centre and is concerned with the higher mental processes. Notice the brain size in relation to the body size of the animals pictured above. In the frog and the bird the cerebral hemispheres are relatively small but in the higher mammals, leading up to man, they are large and their surface is convoluted so that as much grey matter as possible can be fitted into the cranial cavity.

specific skills acquired by instruction and training as they do on "g."

General mental ability grows during the early years of life, but ceases to develop at about the age of sixteen in the majority of children.

Although human intelligence is immeasurably superior to that of animals, we find that animals do give examples of this seeing of relations. The old view that animals act by instinct and man by reason has been shown to be an undue simplification.

The view formerly held that animals learn merely by trial and error can no longer be accepted. Although animals, say a cat in a cage, or a dog in a fenced yard, will spend a long time (as indeed would human beings) in miscellaneous movements of endeavour to escape until ultimately the latch leading to freedom is discovered, there is evidence that after this period of trial and error the solution is more or less suddenly seen.

And the successful movement—say pulling a loop which opens a latch—is not merely a fixed mechanical movement. A cat, for example, which has learned that pulling a loop means freedom, will sometimes pull with her claws, and sometimes with her teeth, thus showing that she has learned the solution of her problem and not merely acquired a fixed mechanical response when certain things are seen.

Most Intelligent Animals

The cleverest animals are the monkeys; and they show clearly in their learning processes that they have seen essential relations.

Thus, a chimpanzee in a cage obtained bananas suspended from the roof, out of reach, by piling boxes one on another for use as a platform. And with the aid of a stick he pulled into the cage a banana on the floor outside. But, even more remarkable, the animal joined two bamboo sticks (each too short to reach the fruit) to make a stick long enough for his purpose. His method is instructive. After vainly trying for about an hour to reach the fruit with the short sticks, he appeared to give up and sat on the other side of the cage playing, apparently idly, with the two sticks.

Accidentally, so it seemed, he jointed one into the other, and then jumped up eagerly, ran to the front of the cage and tried to bring in the fruit with the tool now long enough. The sticks fell apart, but he rejointed them and succeeded in his task. There seems to be clear evidence that the solution of his problem flashed upon him when he first jointed the sticks.

Animals' Limitations

Although animals undoubtedly possess intelligence, we should beware of reading more intelligence into their actions than is really warranted and should remember Lloyd Morgan's canon of interpretation of animal behaviour: "In no case may we interpret an action as the outcome of a higher psychical faculty, if it can be interpreted as the outcome of the exercise of one which stands lower in the psychological scale." But, making full allowance for this,

CHIMPANZEE LEARNING TO WALK

Although monkeys are the most intelligent of all animals and can be trained to behave almost like human beings, they are incapable of learning to talk, read or to write.

MECHANICAL ABILITY TEST

Candidate for an army course is given a test to show his mechanical ability. He has to assemble in the shortest possible time the components of several simple mechanical objects, such as a bicycle bell or door lock, a test of dexterity and quick seeing of relationships.

it does appear that certain animal behaviour is of the same order as intelligent human behaviour. Human behaviour is, of course, vastly superior for many reasons.

In general, an animal's observation of a situation is inferior to man's. Man observes many things quite outside the ken of animals. He also weighs up a problem and exercises control of the means at his disposal in a manner quite impossible to an animal.

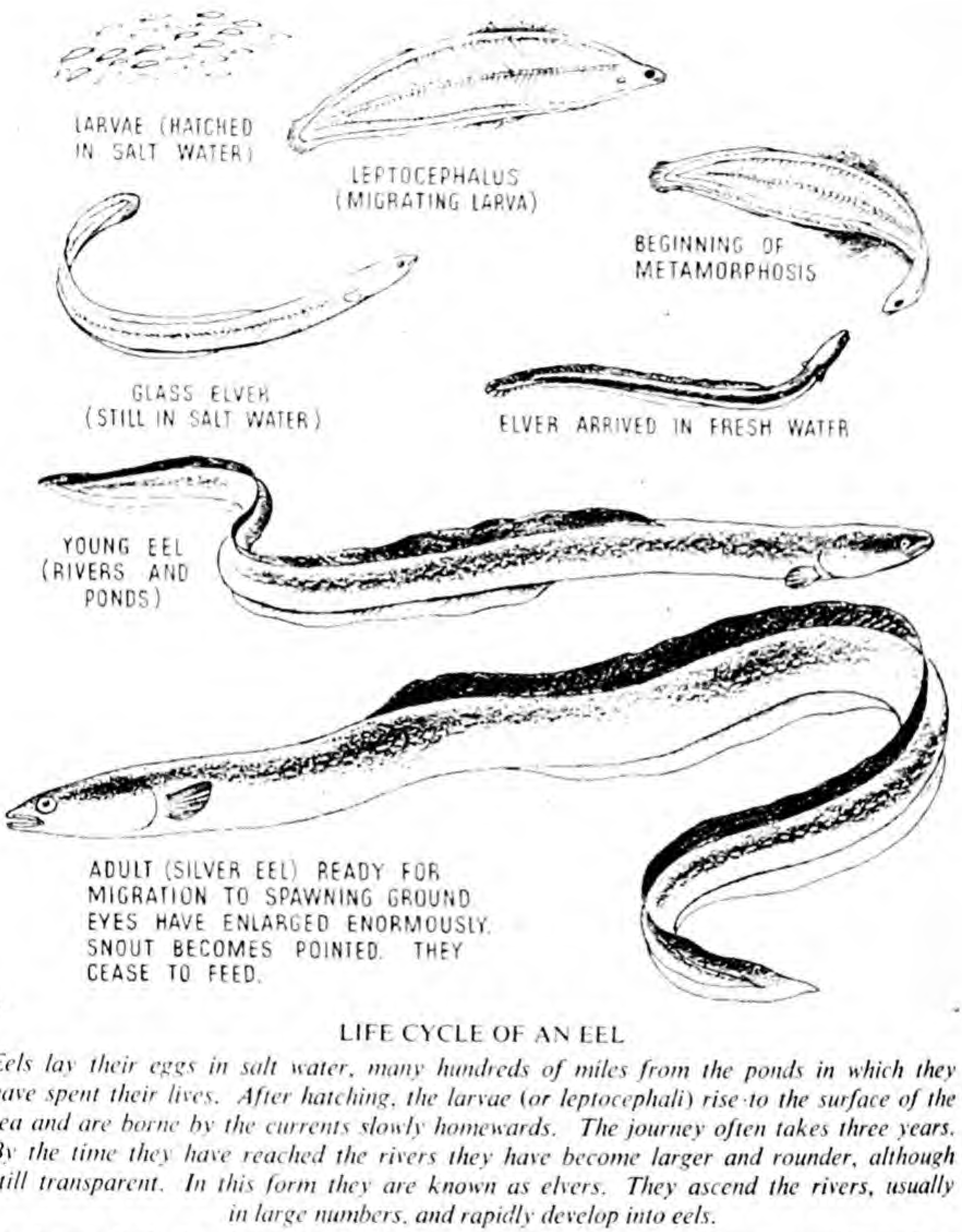
Acting on Instinct

We have been reminded that the old view that animals act only on instinct and man according to reason was unsound, as animals in fact exercise intelligence; but the view is also unsound on another count, as man is undoubtedly a creature of instinct. This used to shock many people, but modern thought has repeatedly stressed the truth that a great deal of man's behaviour is motivated by instincts, or unlearned motives as some psychologists prefer to call them. For example, what an unhappy place the world has been made in this twentieth century by man's unreasoning lust for domination, by his fear and acquisitiveness.

When you say "I did it instinctively," you usually mean "I did the right thing without thinking"; and this illustrates the fact that we do not need to learn to behave instinctively, the pattern of behaviour is inherited. In fact, instinctive behaviour is a kind of inherited memory. We each have our own personal memory; but, in addition, we have had handed down to us certain ways of behaviour which our remote ancestors found necessary to preserve and maintain life.

Many fascinating examples might be given of complicated instinctive activity of animals, but we will content ourselves with mentioning the breeding migration of eels.

In the autumn, mature eels leave the



LIFE CYCLE OF AN EEL

Eels lay their eggs in salt water, many hundreds of miles from the ponds in which they have spent their lives. After hatching, the larvae (or leptocephali) rise to the surface of the sea and are borne by the currents slowly homewards. The journey often takes three years. By the time they have reached the rivers they have become larger and rounder, although still transparent. In this form they are known as elvers. They ascend the rivers, usually in large numbers, and rapidly develop into eels.

ponds in which they have lived for about ten years, and sometimes crawling for a mile or more over damp grass to the nearest stream, travel down to the sea and then are led by instinct to their breeding places in the depths of the sea. Eels, for instance, from England make their way across the Atlantic to West Indian waters.

After spawning, all the eels die. The eggs hatch and the tiny fish slowly make their way homewards to the rivers and ponds from which their parents came about three years before.

About ten years later, they themselves make the journey from pond to ocean, breed and die.

We assume that the eels act as they do without thinking why they are so acting. This reminds us that an important difference between the instinctive behaviour of man and of the animals is that man frequently has a more or less clear idea of

his purpose, whereas animals seem to be impelled blindly.

A definition of instincts will now be helpful; and we shall consider the famous definition by W. McDougall. It states that an instinct is an inherited disposition: (1) to pay attention to objects of a certain class; (2) to feel in relation to the object a feeling of a particular quality; and (3) to act in a particular way in regard to the object or at least to feel an impulse to such action.

To illustrate: the fear or danger instinct, or instinct of escape as it is also called, impels us: (1) to attend to any object which may be dangerous; (2) to feel the emotion we call fear; and (3) to escape from the object—perhaps by running away or putting some barrier between ourselves and the object. Another instinct, say the parental or protective instinct, impels us: (1) to attend to a helpless child, or even animal; (2) to feel tender feeling; and (3) to protect the child and minister to its needs.

Examining the Stimulus

The object arousing an instinct is called the stimulus, and in behaving instinctively man examines the stimulus more carefully and intelligently than does an animal in its responses, which are more automatic and blind. On the highest level it is the *meaning* of a stimulus which arouses an instinct. The response is not a merely mechanical and automatic response to a particular object. Thus, the instinct of fear or escape is aroused by a variety of objects—a mad bull, a car out of control, the wail of a siren—all of which have the same *meaning*, danger. The meaning of a few words in a telegram can arouse very deep stirrings of instinctive emotion. In a new-born child fear is aroused only by a harsh noise, and loss of support.

The instinctive impulses are of fundamental importance; not only in maintaining the life of the individual and of the race, but in providing the raw material of which character is fashioned.

McDougall in his *Social Psychology* gives a list of instinctive impulses which is of great assistance in studying human behaviour. He describes fourteen primary instincts; they are flight (fear); pugnacity; repulsion (disgust); parental instinct; appeal; sex; curiosity; submission; assertion and self-display; gregariousness; food seeking; acquisition; construction and laughter. Each of these tendencies operates in the way we have mentioned when defining instinct. Thus each has its appropriate stimulus, is accompanied by its appropriate quality of feeling (the emotion) and has its appropriate action or impulse to action.

Constructive Instinct

Further to illustrate our point; this time with regard to an impulse which is less prominent than others, as the majority of people are denied many opportunities of its expression—the constructive instinct. Any material which can be handled and used as raw material will arouse this tendency to construct things; and there is a real satisfaction experienced in the making quite apart from the usefulness or otherwise of the object made. Children love making things—from mud-pies to Meccano models, and their elders experience a similar satisfaction in knitting, woodwork, constructing buildings and organizations, and formulating legal codes.

There are other shorter lists of instincts, based on our fundamental needs. We thus have the self-preserving, race-preserving and herd tendencies or ego instincts, sex instincts and herd instincts.

An important word of warning must be given. It must not be assumed that in describing a number of instincts we are suggesting that the self is divided into as many parts. In fact, the various instincts should be regarded as different expressions of one life force or energy—called by some people the libido.

Interpretation of the Libido

This libido has been identified by some psychologists as the will to live, that energy which "sleeps in the mineral, dreams in the plant, wakes in the animal and becomes conscious in man." In the view of others, the libido is mainly sexual; some identify it with self-preservation; others with the will to power. But any attempt to explain

human behaviour in terms of one tendency only is an over simplification and is misleading.

In Chapter VII, the conditioned reflex is described. Instincts, too, can be conditioned, that is, can be aroused by a conditioned stimulus; a stimulus other than the natural one.

A little boy, not yet one year of age, was accustomed to playing perfectly happily with dogs, rabbits and white rats. An experiment was tried in which the white rat was held out to the boy. He at once reached for it and at the same time a loud rasping noise was produced just behind the child. He was frightened at the noise. After this had been done a number of times, he showed fear of the white rat even when it was offered him in perfect silence. Further, he had also become conditioned to fear the rabbit and the dog. Many of our fears are acquired in this way; in fact, as we have mentioned already, a new-born baby fears nothing except a harsh noise and loss of support.

This principle of conditioning applies, of course, to all the instincts. An interesting example is our attitude to symbols—a flag, a badge, a school tie, even religious symbols such as the Cross. The symbol by conditioning arouses in us the devotion or reverence which is our appropriate attitude to the object for which the symbol stands.

Expressing the Instincts

An important difference between man and the animals is in the manner of expression of the instincts. Both man and the animals express them on the physical level, in the natural way. Dangerous objects arouse fear, strange objects curiosity, the mate arouses the sex impulse, a more powerful creature arouses submissiveness and so on. But man can also express the impulses on a higher level.

Although the energy used is the same as that used when expressing an impulse naturally, it is now directed to a higher end. Thus, the assertive impulse which in its crude expression would seek to dominate any weaker person, can be expressed in helpful leadership. The sex impulse, the constant expression of which on the natural level is manifestly impossible in civilized society, can be expressed in creative work for the good of the community.

This process of redirecting an instinctive impulse is called sublimation or lifting up above the level of mere personal gratification. Being civilized, we know that we cannot on every occasion express our impulses naturally. The civilized man is distinguished from the savage and from the animal by his self-restraint.

Surplus Energy

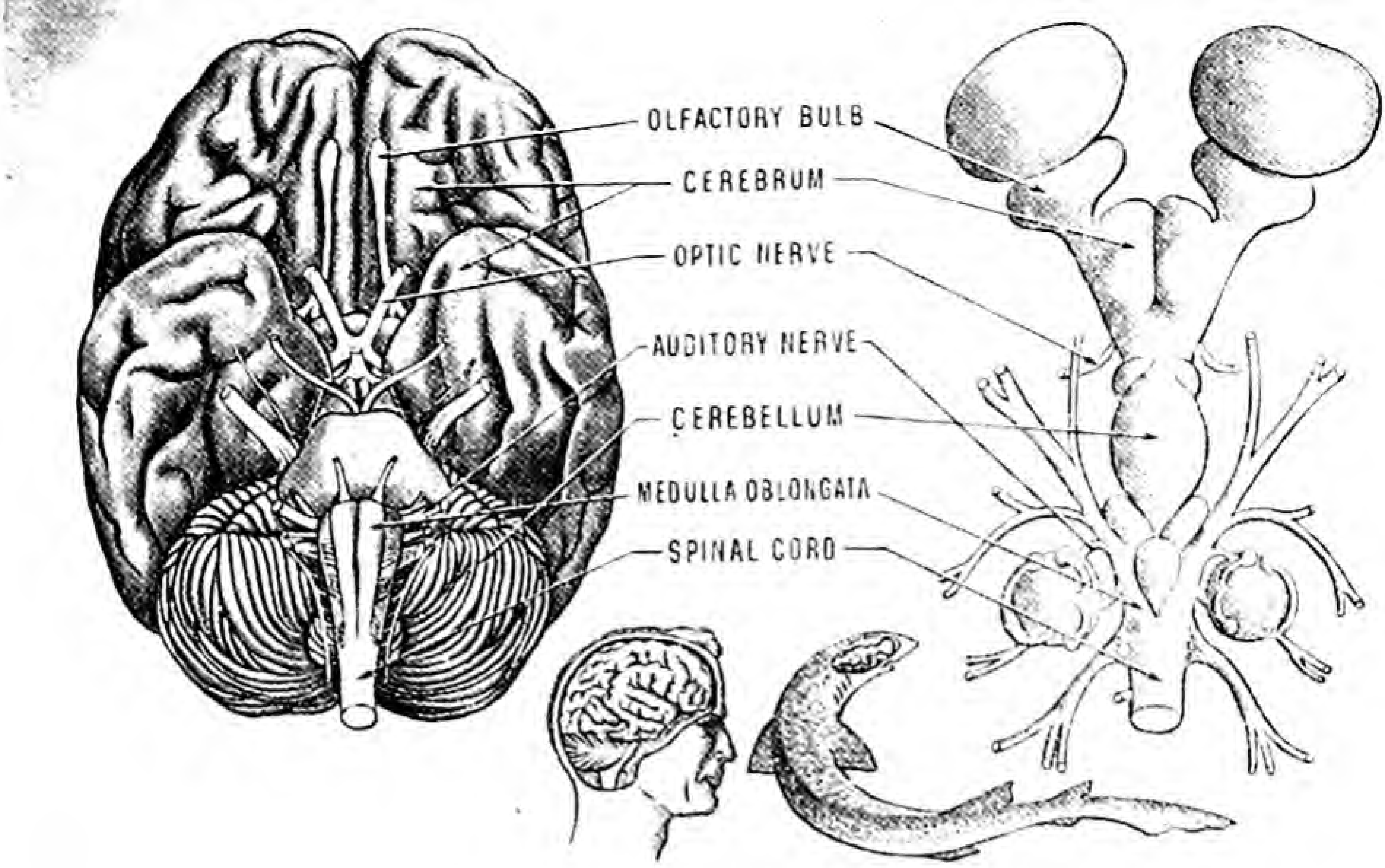
The instincts serve the great end of providing for our physical and biological needs, and the progress of civilization has been accompanied by a lessening of the amount of instinctive energy required in satisfying these needs. This has left civilized man with a surplus of such energy demanding expression, which must, therefore, be sublimated. Some of this surplus energy has been expressed in the art and learning which have enriched the life of man.

The great advantage of a satisfactory redirection of instinctive energy is that the personality is strengthened instead of being buffeted by the conflict of crude impulses.

Instinctive energy can be likened to a swift mountain stream. The stream, if allowed to rush unhindered down to the valley may cause, especially in time of flood, great damage to property and danger to life. But this same stream, if canalized and led through pipes, will drive electrical generating machinery which will bring light and warmth to people of the valley. The energy of the stream is unchanged, but its new direction makes all the difference.

Similarly, the restless and destructive energy of the young hooligan can be redirected under the influence of an ideal, to socially helpful ends. In sublimation, then, an instinct is diverted from its natural end to ends which are satisfying to the individual and are of value to the community.

We have seen that the instinctive impulses can be regarded as a kind of racial memory; we are born with them. But, of course, this is not the whole story, as our



EVOLUTION OF THE BRAIN

Brain of a man and that of a dogfish compared. The olfactory lobes are concerned with taste and smell, while the cerebrum is related to the higher powers of thought. Note that these regions differ greatly in size in the two living things considered here. A dogfish finds its food principally by its taste and smell; it has a low order of intelligence.

instincts become embedded in habits which are not inherited but acquired.

Animals, too, acquire habits. A dog which sees his master take his hat and stick off the peg may at once run to the door.

Importance of Habits

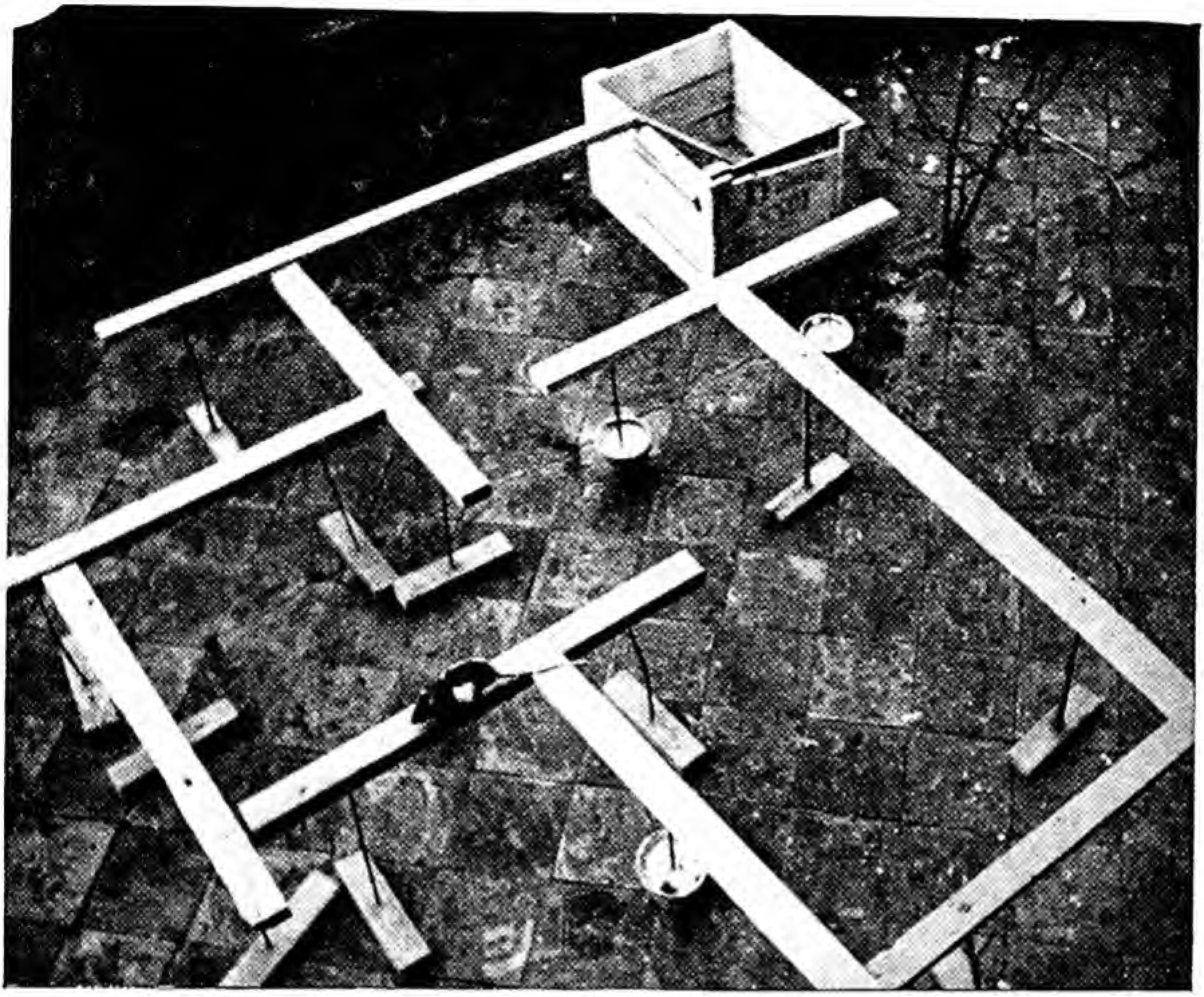
Man's habits, whether of body or of thought and conduct, are vital to his development. This was the view of the Duke of Wellington who said "Habit a second nature! Habit is ten times nature!" Habits are great labour-saving devices, as the more habitual an activity becomes—say typing or cycling—the less thought has to be expended on it; one might say that the unconscious mind has taken control.

The experience of William James, the great psychologist, illustrates this. He was in Paris for the first time for ten years after he had attended school there, and was walking past this school when he forgot his surroundings and wandered on, day dreaming. He came to himself later, on the stairs of the house a long way from the school at which he had lodged when a student ten years before. The sight of the familiar school had set in train his habitual activity of walking to his lodgings every day.

Habits are automatic, largely free of conscious control. Therefore, it is important that we should acquire right habits. On these is built character, which has in fact been defined by one psychologist as the interpretation of habits.

We have indicated that we acquire not only physical habits but mental habits. The latter may be illustrated by the story of the amateur detective who offered to guess the professions of his fellow passengers in a crowded railway compartment if they would give him two meanings for the word "box." Everyone began by describing a box as some kind of receptacle; but the second meanings given differed widely and revealed the thought, habits and professions or personal interests of the passengers.

A lady, obviously "in the profession," said that a box is "the best place in a theatre." The schoolboy thought it was "something you got on the ear." The postman said it was "something received at Christmas." The pugilist thought it meant



INVESTIGATING THE ANIMAL MIND

Experiment with rats. A labyrinth was arranged of narrow slats of wood leading by devious paths to a box containing food. After three attempts the rat found the shortest way to the food and thereafter took the short cut every time. This does not necessarily imply reasoning on the part of the rat, but rather the quick formation of a habit.

"fighting with the fist." The American baseball enthusiast explained that the box is the "square where the pitcher stands." The motor mechanic spoke of gear boxes; the soldier of a sentry box; the sportsman of shooting boxes.

The exploration of a person's habits of thought by noting the words he gives in response to various test words, is put to practical use in the treatment of neuroses, or nerves, as the ordinary man calls them.

As we go through life we acquire habits of thinking, feeling and acting with regard to things, persons and ideas. In other words, instinctive emotions become linked to or grouped round various objects. If the linkage is healthy we call the group a sentiment; if unhealthy, a complex. In everyday speech, we may not often use the word sentiment with this meaning, but we do use such terms as likes, dislikes, loves, interests, passions with regard to various persons, things, ideas.

Parental Feelings

For example, a man has a sentiment of love for his child in which various instinctive emotions (parental tenderness, self assertion and gregariousness) are grouped round the idea of his child. Whenever he sees his child, or thinks of him, he habitually feels in a particular way with regard to him and this feeling is a blend which includes the emotions mentioned.

The confidence and affection a dog shows towards his master, so different from the habitual fear and anger he evinces

towards a stranger who has hurt or frightened him, show clearly that he too has acquired habits of feeling.

An important difference between the sentiments of a human being and those of an animal—although, of course, we have no certain knowledge of the mind of an animal—is probably that in a human sentiment there is an idea of the self: the man conceives his love or dislike as his. It is doubtful whether an animal, on the other hand, has any consciousness of itself.

John Smith says "I love my dog" and is aware of himself as a self-conscious being loving his dog; the dog loves his master, but this may merely mean that the sight or sound or smell of his master arouses pleasant feelings. We cannot assume that he is aware of himself as a being having any relationship with his master.

Our most important sentiments are our moral sentiments: our love of truth, beauty and goodness; and here we reach the most important distinction between men and animals. Animals have intelligence, and some creatures are thought to have a sense of beauty; but man, in his possession of a moral sense, a judging of actions to be right or wrong, is sharply differentiated from the animals. Still further, he has a sense of the sacred. He can respond with his whole being to a quality or spirit in the universe which evokes his reverence.

We are so made that we feel we must seek after what we call higher things. However much we argue as to the precise nature of the good, we have a conviction which we will not give up, that there is an objective right; that morality is not a mere matter of custom or of feeling; that this right exists independently of man's thinking of it. All of us, whatever our characters, when driven into a corner must admit that one action is on a higher level than another. When pressed for a reason, all that we can say is that action A is right; action B is wrong.

Man is guided by conscience—however ill-instructed some consciences may be. Conscience informs us whether or not an act is in harmony with one's ideal, with one's self respect.

But some will ask, is man free to choose the right, has he free will? Are not his actions rigidly determined by his heredity and environment? Those who argue that we have no free will argue very logically and we may find it difficult to refute their arguments. But although beaten by logic we finish by saying "And yet I am free."

We obviously have not complete freedom; we are limited by our physical environment, for example; but it is merely playing with words, to say that we cannot choose the right as we see it. No man can honestly say that he *must* do an underhand trick.

To deny freedom of choice is, of course, to cut at the basis of all law and morality. If a man cannot choose, it is absurd to call him to account; even the most bigoted opponent of the doctrine of free will, will surely want to hold responsible a person who has burgled his house.

Test Yourself

1. Which of man's activities distinguish him from the rest of the animal kingdom?
2. What are the two factors upon which intelligent behaviour depends? How would you define an intelligent person?
3. What is instinct? Give one example of instinctive behaviour.
4. Give two examples of instinctive impulses undergoing sublimation.
5. On what principle are modern intelligence tests based?
6. McDougall in his "Social Psychology" listed fourteen primary instincts. Write down as many of these as you can remember.

Answers will be found at the end of the book.

COURTSHIP IN THE BIRD WORLD

Courtship plays a great part in the life of birds and some species seem to make love for two seasons before actually mating. Feeding of the female by the male is commonly part of the courtship between them. In this picture a male great tit is seen placing food in his mate's beak.

CHAPTER X

COURTSHIP AND MATING

THE subject of new life, and how it comes into being, is one of the most enthralling in the world and, to many, one of the greatest of life's mysteries.

At one time, in fact until comparatively recently, it was believed that among the lower forms of life new creatures arose spontaneously, that is to say, from lifeless material. It was not until the nineteenth century, largely as a result of experiments conducted by Pasteur, that this theory was finally disproved.

No one can say how life upon the earth first began, but scientists believe today that all life is derived from life, that is, that new living things can arise only by a process of reproduction from living things of the same sort.

There are two main processes of reproduction, sexual and asexual, that is, with or without sex. Man and the higher animals all reproduce with sex, but numerous plants as well as the lower forms of animals reproduce themselves asexually, although asexual reproduction is occasionally found as high in the scale of animal life as some of the insects. The pupa of a midge, for example, can lay eggs which will hatch and develop into adults. These creatures also reproduce sexually in the adult stage.

Reproducing by Division

The simplest form of reproduction is by what is known as fission. In this process the organism divides into two halves, each half continuing thereafter a separate life of its own. In due course, the new individual splits again, and so *ad infinitum.*

Some plants and simple animals are able to reproduce by growing a bud, which eventually becomes detached and forms a new individual. This is known as budding. Sometimes both sexual reproduction and budding are employed.

Some lower forms of animals, such as the common sponge, can be reproduced from cuttings, like plants; this is called vegetative reproduction. A few relatively much higher creatures, for instance the planarian worms, seem literally indestructible. If one of these be cut transversely into several pieces, each grows a new head and tail, and the apparent end of the original worm results in a team of new worms! Some animals have the power to regenerate an organ if it is cut off. A starfish, if it loses an arm will grow a new arm in its place; more amazing still, the arm that has been cut off will develop into a new starfish.

We find some strange variations played upon the themes of sex and sexlessness. The common garden snail, for example, is a hermaphrodite, yet spring always sees these creatures in pairs, raised one against the other, foot to foot ; sometimes three may thus combine. In this attitude, maintained for a long time, they stimulate each other by the injection of little flinty javelins termed love darts.

Some molluscs (the oyster and its chief enemy, the slipper limpet, are familiar examples) change sex rhythmically with succeeding years.

Virgin birth, or parthenogenesis, is a commonplace with many animals. The female greenfly can produce several generations without the intervention of a male. Bees are also to some extent parthenogenetic. The queens and the workers, which are only undeveloped females, come from normal eggs, but the drones, the male bees, are derived from unfertilized eggs.

Even where the two sexes are well defined, ordinary contact is not necessarily indispensable. Skate and dogfishes mate almost like cats or cattle, but the males of the higher fishes spray with milt the eggs as they are extruded by the female, a most wasteful form of reproduction. Some creatures laying relatively few eggs take fantastic steps to ensure their fertilization. The male of the tiny book-scorpion places its sperm in a sort of wine glass or

membraneous chalice, which is presented to the female.

The males of some little fresh-water fishes take the milt in an organ rather like a tongue and insert it in the female's mouth, where it is later joined by her eggs, previously laid in some secret recess. Incidentally, the females of certain flat fishes may on occasion level up the sexes, by taking on the duties of males, their anal fins serving the purposes of intromittent organs. The male of the common newt, after a most fantastic love-dance, deposits his sperm in the form of a small capsule, which the female picks up and puts in close proximity to the eggs within her.

The males of all mammals, birds, reptiles, practically all insects, and some of the fishes and water arthropoda, deposit the sperms directly into the bodies of the females. This is the better to ensure fertilization of the egg.

Wooing Devices

Some of the devices to which animals resort to attract members of the other sex are very curious.

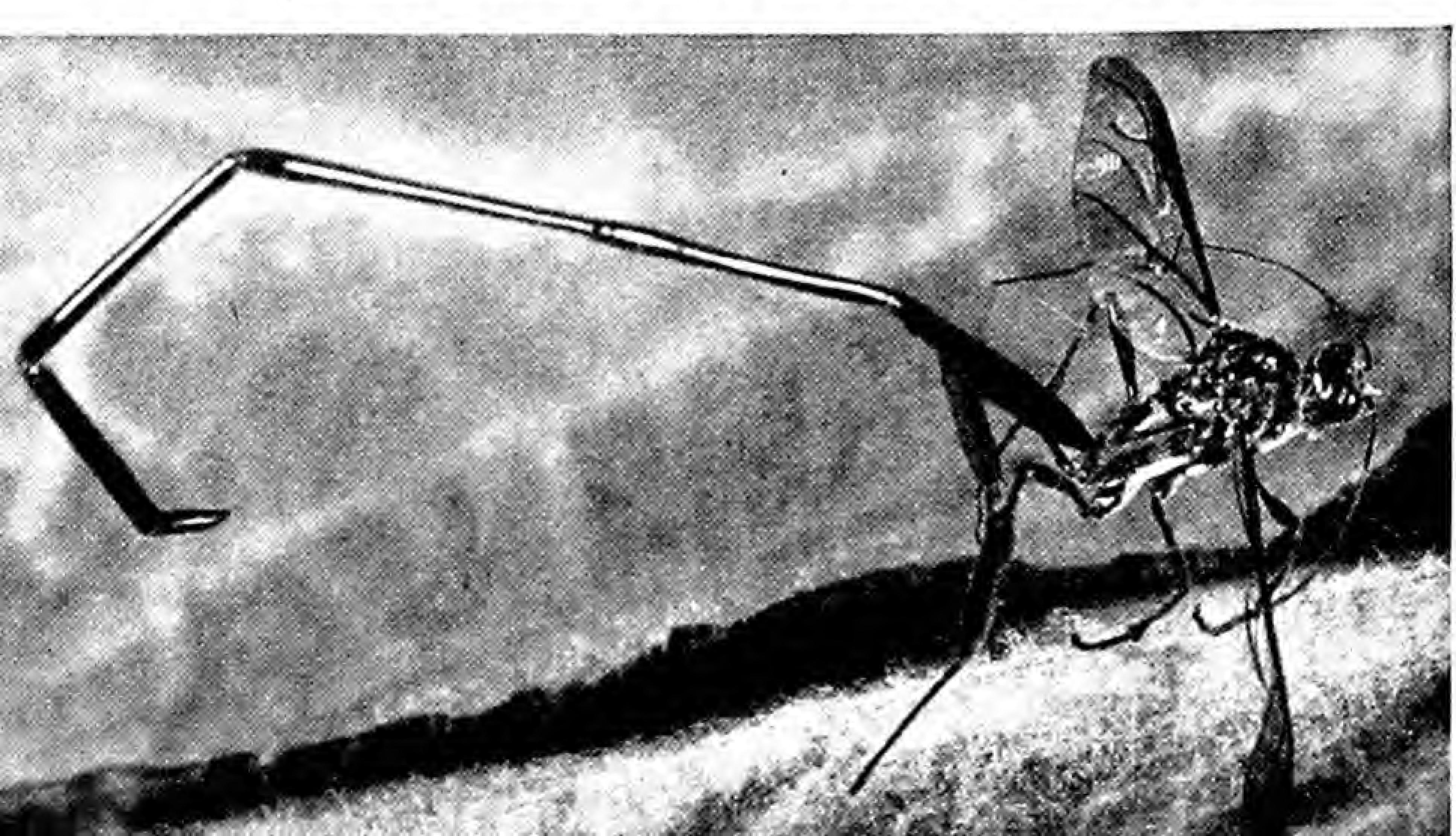
The wooing of the fiddler crab, a creature that swarms on every tropic and sub-tropic shore, is amusing. The male has one claw twice the size of its whole body, which it flourishes before the lady of its choice with tireless persistency until she signifies her acceptance. Among spiders, courtship is rather a gruesome affair. The female is much larger than the male and if she gets a chance she will eat him, even before the marriage has been consummated. Consequently, the unfortunate male spends his wooing in alternately seeking to attract the lady with fantastic dances and flying for his life.

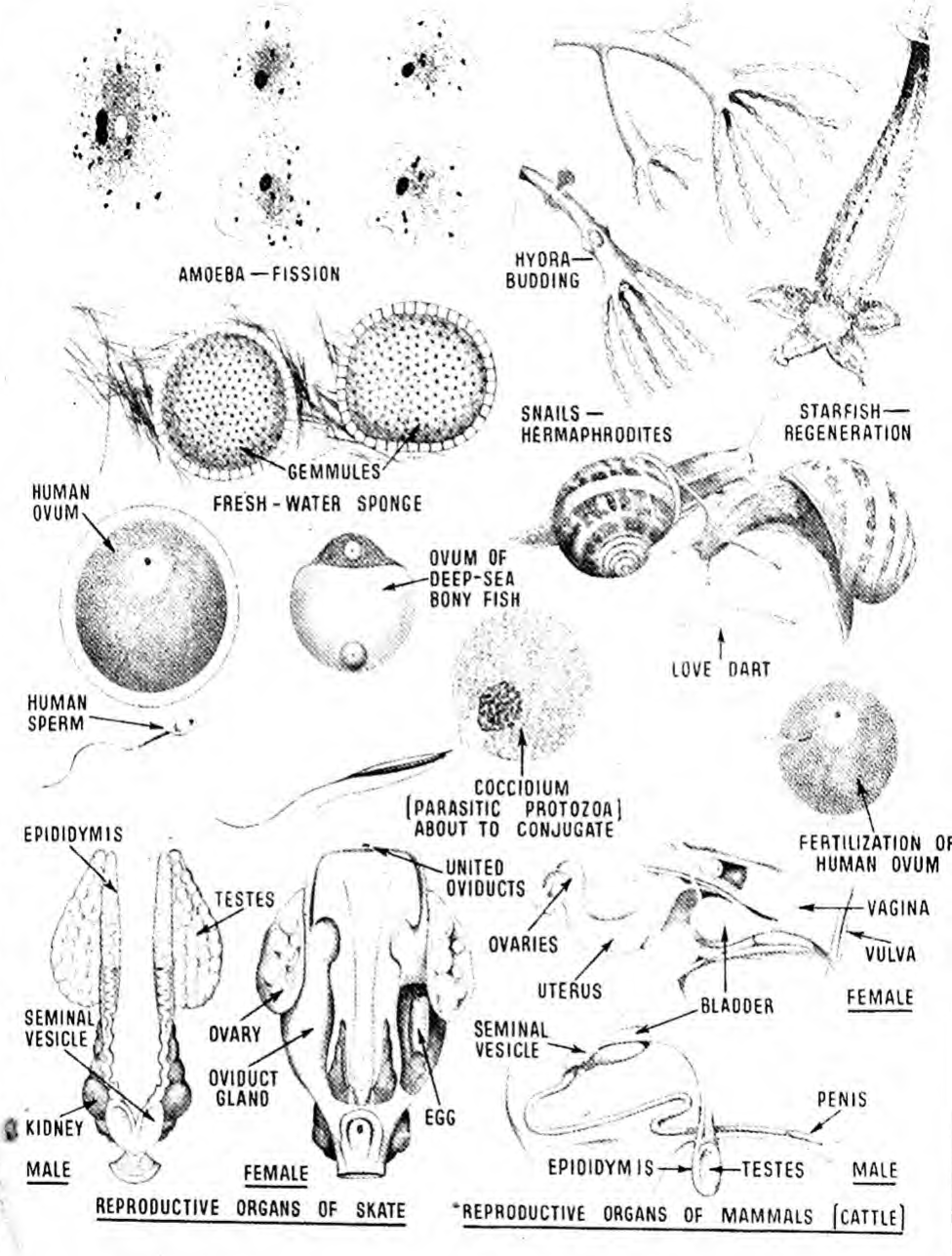
It seems likely that the female spider's ferocity is prompted by the urge to fortify herself against the strain imposed upon her in egg production. The same instinct probably also animates the female praying mantis, who sometimes devours her partner even whilst their union is being consummated.

Other devices adopted by the higher insects are more attractive. The female glow-worm lures her lover by a light emitted from her abdomen. The male empid, a small carnivorous fly, will bring little offerings (usually in the form of food) to his lady love enclosed in little bubbles of fine silk spun by himself from secreted material. Often he will fly hither and thither before he finds an appreciative mate. Sometimes

EGG-LAYING APPARATUS

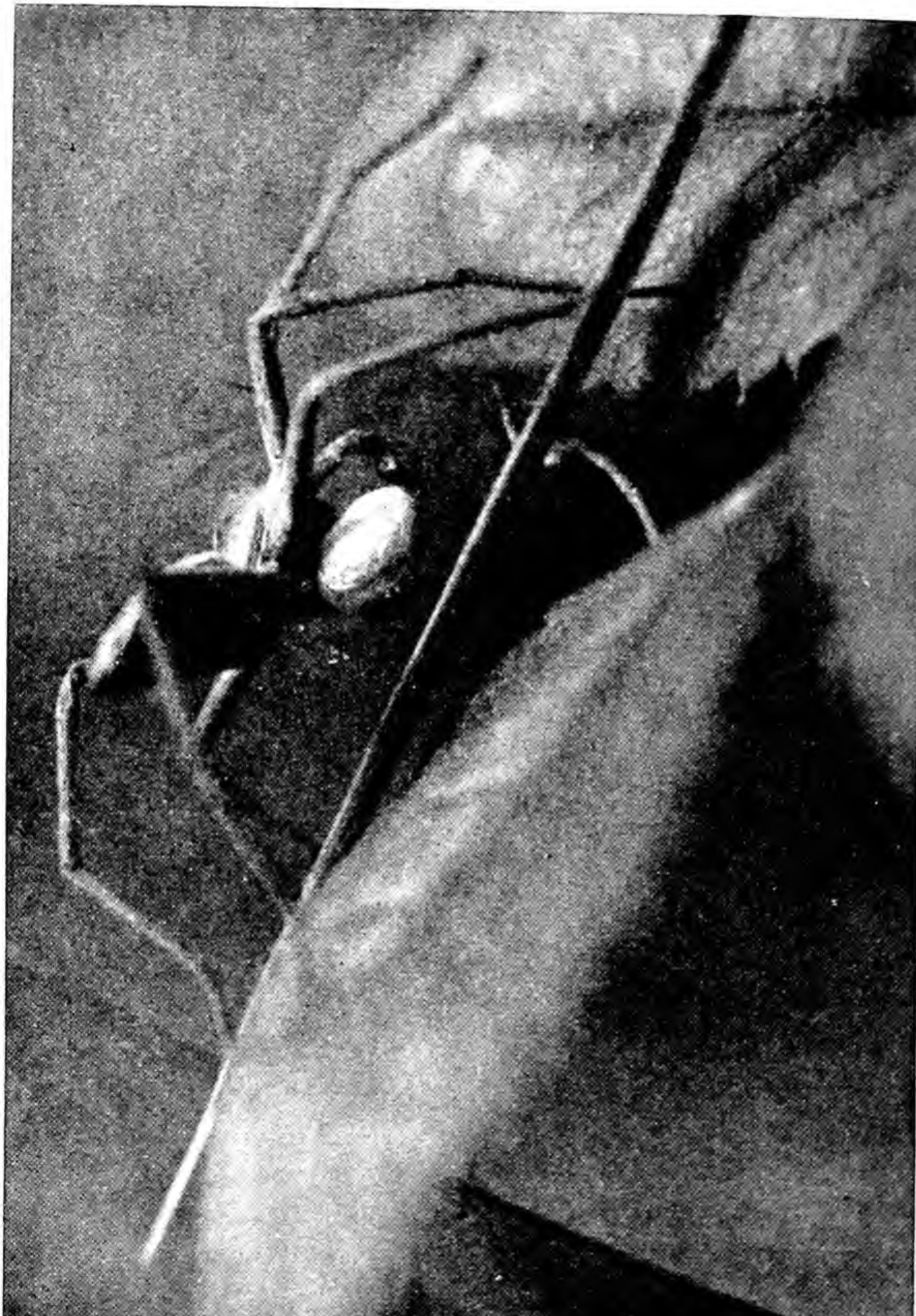
The female ichneumon fly has a long egg-laying apparatus, called an ovipositor, at the hinder end of the body. Many of these flies lay their eggs in the larvae of other insects. This particular species drills holes in wood and lays its eggs in the holes.





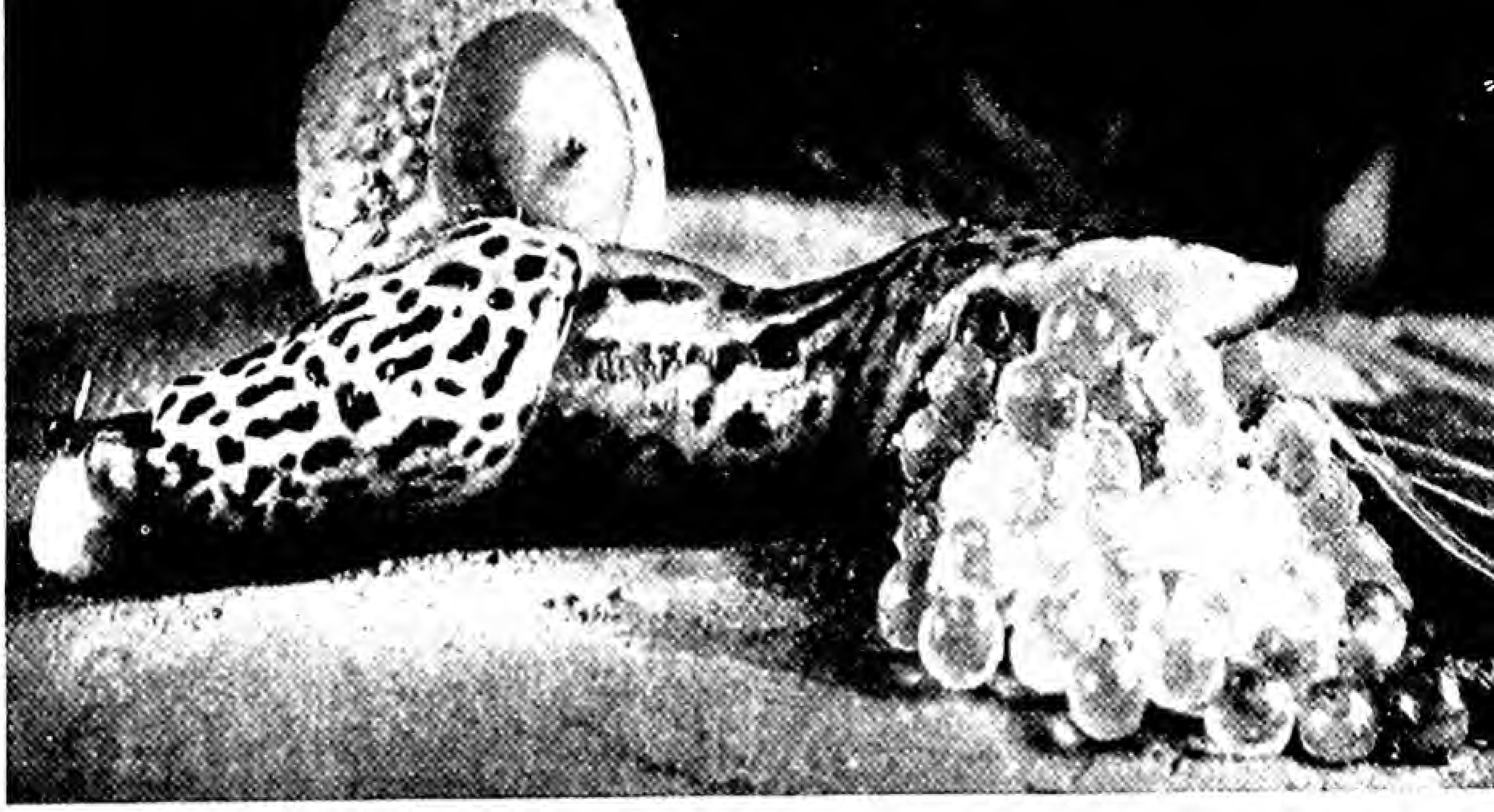
HOW NEW INDIVIDUALS ARISE

Reproduction in animals is achieved in various ways, and it can take place with or without the intervention of sex. Asexual reproduction is more common in the more primitive organisms. Sexual reproduction is the only method found among the animals with backbones. Mammals deposit the sperm inside the body of the female to ensure fertilization.



SPIDER AND ITS EGG

Spiders spin silken cocoons and lay their eggs in them. In this picture a hunting spider is shown carrying its egg with delicate care. It will guard it jealously. Courtship among spiders is a stormy affair and the female will attack and even devour the male.



SLUG LAYING EGGS

Slugs, like snails, are hermaphrodite, each individual containing the reproductive organs of both sexes. Therefore each individual can lay eggs. A black slug is shown laying its batch of eggs. It produces large quantities of these gelatinous globules.

his offering takes the form of some small, brightly coloured trifle.

Many fish indulge in the most fantastic posturing and contortions, usually accompanied by the temporary assumption of a suit of gaudy colours. The little stickleback is a passionate and most amusing wooer. But fish, true to their nature, are essentially cold-blooded creatures and have no further use for their mates once the marriage has been consummated.

Birds are in some respects the most remarkable members of the animal kingdom. Their mating and breeding are full of interest.

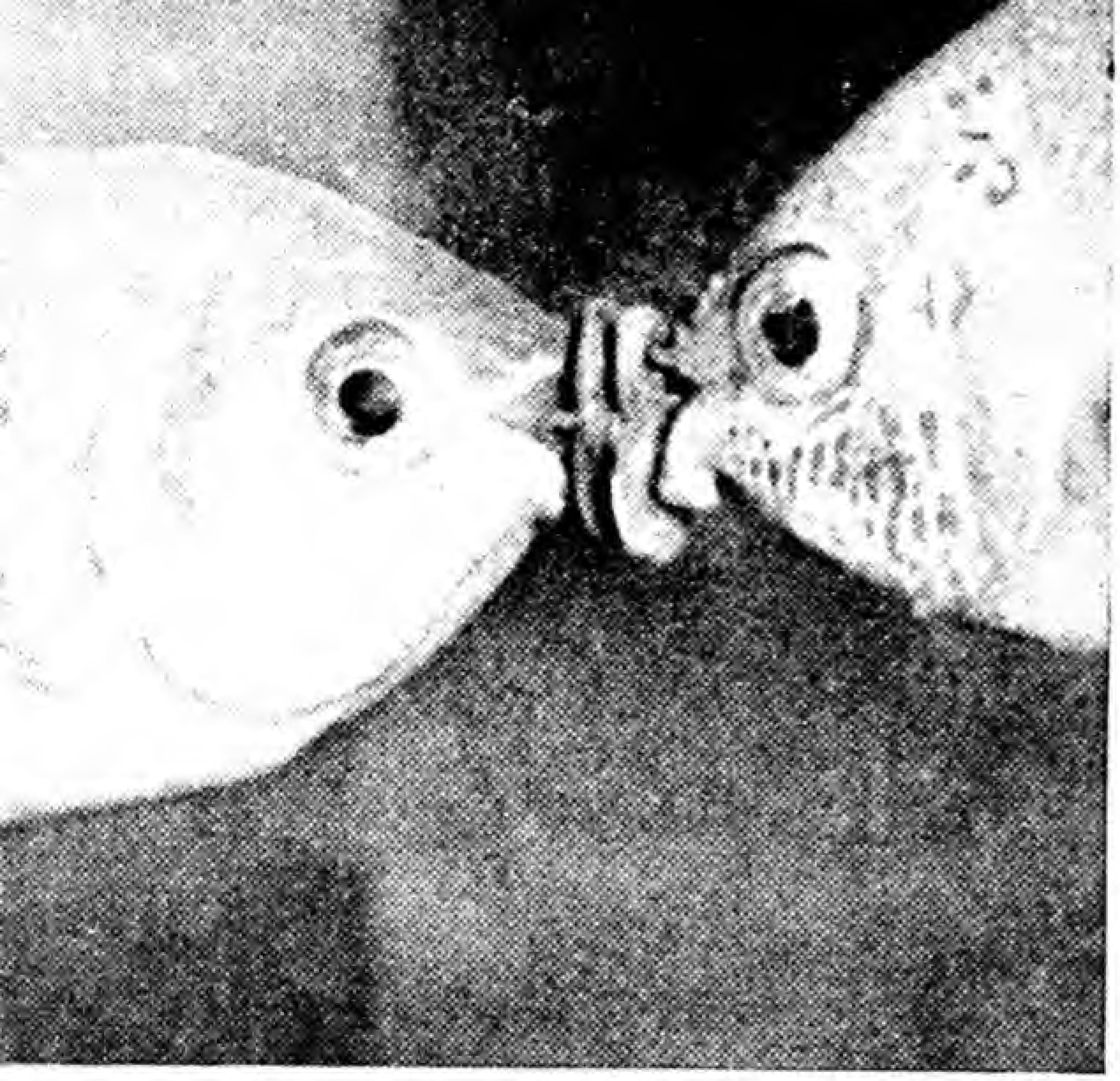
A bird will lay eggs without mating, but these eggs will be infertile. A white-tailed eagle in a certain zoo was for ninety years believed to be a male bird. At the end of that long period she laid her first egg, which was, of course, infertile since she had no mate. Mating is a joyous thing for birds. The act of mating is often a swift and carefree one, free and delicate almost as the air through which birds fly. Most birds mate on the ground or on trees, but there are exceptions. The swift mates in the air, at a considerable height, both birds screaming as they fall. Many sea birds mate on the water, as do grebes, ducks and other birds more at home on water than on land.

Mating takes place before the eggs can be fertilized, but the act of coition may continue at intervals through the period of incubation, as at intervals during the period of nest-building. Not by any means all birds make nests. The long-tailed titmouse usually takes weeks to construct its domed nest, lined with feathers to the number of between one and two thousand. What a contrast is that beautiful home to the simple hollow scraped by the oyster-catcher, a hollow that is sometimes lined with rabbit droppings. The oyster-catcher does, indeed, at times make a primitive attempt at a nest, but a number of species make no nest at all.

Breeding of Sea Birds

Let us consider the most numerous sea bird in Britain—the guillemot. This bird breeds in immense colonies on sea cliffs or stacks around the coasts. The birds sit on their large, pear-shaped, often beautifully marked eggs, so close together that they touch. There is no nest of any kind. The egg is laid on the rock, and is there incubated, held penguin-like on the bird's feet. When a guillemot colony is suddenly disturbed from above and the birds fly in alarm out to sea, some of the eggs are almost always pushed off the ledges and are broken on the rocks below.

Why is it that some birds lay one egg, and others, such as the corncrake, ten or twelve? The reason may well be that those



KISSING FISH

Here are two fish which seem to kiss like a pair of film stars, though in the case of the fish the purpose of the kissing is not known. The kissing gourami lives in the Malayan region. It has an accessory respiratory organ which enables it to live for some time out of water.

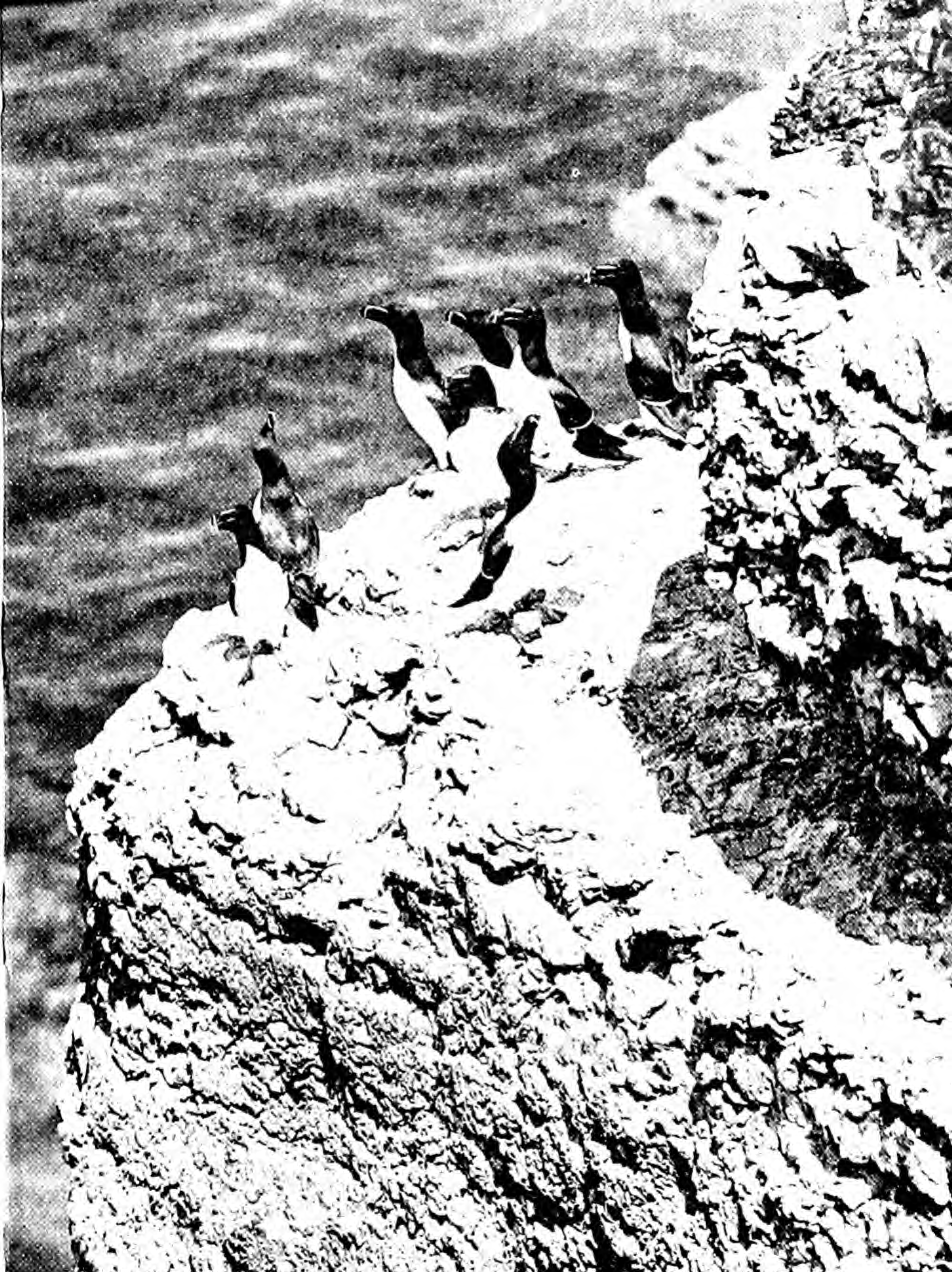
birds laying the most eggs have the greatest number of enemies. Let us take two examples, the corncrake and the fulmar. The corncrake nests in fields of hay and corn. It lays ten to twelve eggs, sometimes even more, yet it is decreasing everywhere, and in some districts is no longer found. Although the young corncrakes run actively from the earliest age, many are taken by cats. The parent birds do not seem to have adapted themselves to new menaces. In olden times the hay and corn were reaped by the scythe, which enabled the parent bird to leave the eggs before she was killed, and also gave her a chance to collect and lead her brood to safety. Then arrived the horse-drawn reaper, which came upon the corncrakes and their young before they had time to escape, and now, a still greater danger, the motor tractor. Only in remote districts, where primitive methods of husbandry are still in use, does the corncrake now hold its own.

At the other end of the scale, let us take the fulmar petrel. The fulmar, a bird of the ocean, lays one egg, and if that egg be removed, or be sucked by a gull or crow when it is perfectly fresh, the bird will not lay a second egg that year. It might, therefore, be thought that the fulmar would be, like the corncrake, a decreasing species. Yet, perhaps more than any British bird, it shows a remarkable increase. In the nineteenth century its only breeding place in Britain was on the remote island group of St. Kilda, lying one hundred miles west of the mainland of Scotland. It is now found breeding round the entire coastline of the British Isles, and each year is forming new colonies. The inference is that the fulmar has singularly few enemies. A greater black-backed gull at times carries off a young fulmar to feed its young, and herring gulls suck the eggs when they have an opportunity, but the percentage of young birds lost must be very small to account for the increase of the species.

Two Ways of Life

The fulmar is one of those birds which make no nest in the generally accepted sense of the word, but scrape out a shallow depression on an earth-covered ledge of rock or lay their egg on the hard rock itself. The contrast of life for those birds of the ocean during the breeding season is remarkable. The guillemot, razorbill and other diving birds, are at sea during the rest of the year and never alight on land. The fulmar in autumn and winter sails above the ocean over the wild waters of the Atlantic from Scotland to Iceland, and over the northern seas from Scotland to Norway and from Norway to Spitsbergen. Then, in earliest spring, it returns to its rock, where it lives, for a period, the life of a land bird.

The mating of the fulmar is a protracted affair; the honeymoon is prolonged. When these birds found a new colony they do not lay the first season, or sometimes even the second. Throughout the spring and summer



CLIFF-DWELLING SEA BIRDS

Most maritime birds come to land only during the breeding season and then restrict themselves to cliffs and rocky ledges. Many of them live in communities, possibly as a means of protection, as these birds often lay only one egg in a season. The photograph shows razorbills on a nesting ledge. They court and mate on the water

NEST THAT FLOATS

The great crested grebe builds a nest of floating reeds which is not easily reached by creatures wishing to plunder the eggs. Moreover, when the female bird leaves the nest she covers the eggs carefully with vegetation and thereby makes them inconspicuous.

months, they court on the ledges, then disappear into the ocean solitudes and are seen no more until early next spring, when they return and have another prolonged period of courtship, again perhaps without an egg being laid. Presumably, these new colonies are founded by young birds which pair—as there is some evidence the golden eagle does—before they are mature.

During this prolonged courtship the fulmars seem to lose none of their ardour. They squat on the ledges, fondling one another with their bills and uttering deep-toned quacking cries, quickly repeated. When the ledges are inaccessible to the human observer it is sometimes hard to tell whether the birds have laid or not, for they do not, like the gulls, stand upright but squat on the ground, as guillemots and razorbills do. It is rare to see a fulmar stand upright, and this it does at most for a few seconds, before subsiding to the usual position.

Some sea birds on occasion make a nest, and on occasion make none. Take for example the family of the terns, sometimes called the sea swallows. The Arctic tern sometimes lays her eggs on the bare sand,

but on occasion shows an aesthetic turn of mind, for she scrapes out a hollow and lines it with the buds and flowers of the sea thrift. On these dark rosy buds and pink flowers the tern lays her two, or perhaps three eggs, delicately marked or spotted, sometimes of a pale, unmarked blue.

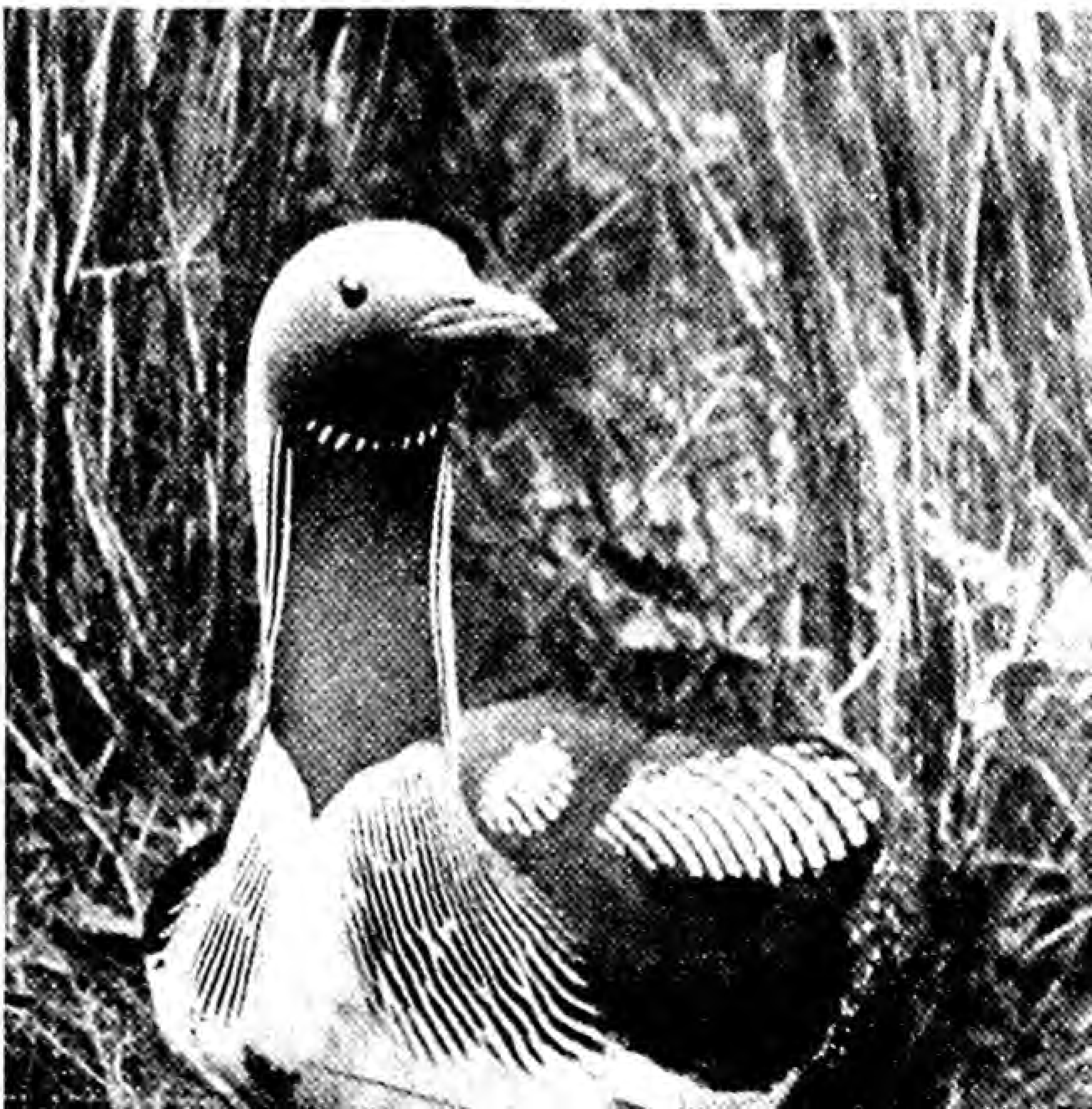
Mating on the Water

Most diving birds perform the act of mating on the water, and it is probable that the fulmar, although it courts on the ledges, mates on the surface of the sea. Guillemot and razorbill mate on the water, so do the black-throated diver and the red-throated diver, the grebe family, ducks, swans, geese and other birds. Razorbills, before mating, court by swimming round one another, sometimes facing each other and touching each other with their bills. The red-throated diver performs feats of swimming and diving during courtship, so do the grebes.

Grebes build substantial nests, which are floating platforms in the reeds. When a grebe is disturbed the eggs are covered with aquatic vegetation by a few quick strokes of the bird's bill and the sitter dives swiftly into the water. Unlike the grebes, the red-throated and the black-throated divers lay their two large, dark eggs at the margin of the loch, where the birds can dive straight from them beneath the surface. Compared with that of the grebes, this type of nesting-site presents two disadvantages. The loch may rise and the water may flood the nest and sweep the eggs away.

The second danger, although not so serious a one, is that the loch may shrink during the diver's incubation period and thus the bird may no longer be able to dive from the eggs into the water. Anyone who has watched either the black-throated diver or the red-throated diver on land knows how handicapped the bird is under these (for it) strange conditions. Its legs are set too far back to enable the bird to walk, and it progresses painfully, mostly on its breast. On Moffin Island in the Arctic, a small, low island north of Spitsbergen, the tide receded far from a lagoon at the margin of which (at high tide) a red-throated diver laid her eggs. At low tide, the diver when disturbed had of necessity to make her way as best she might some distance overland before she reached the friendly sea.

Moffin Island is rarely disturbed by the human race, but on the occasion when the writer visited it with the Oxford University Expedition he saw, after landing on the island, a pair of red-throated divers approach the shore of one of the lagoons. On reaching the margin of the water, one of the divers scrambled on to the land and progressed with a ludicrous, ungainly motion over the ground, moving along with laboured leaps and more than once falling forward on her breast. The distance from the water's edge to the eggs was



LOCH-SIDE NEST

Divers breed on inland waters and frequently lay their eggs close to the water so that they can dive in straight from the nest. A black-throated diver is shown on her water-side nest.

measured and found to be twenty yards—an exceptional distance for a diver to have to travel over the ground.

Compare the primitive nesting hollows of the divers, terns and fulmars, with the comfortable and elaborate nests of other birds. The willow warbler, the long-tailed tit, and other small birds—even the house sparrow of untidy nesting habits—line their nests warmly with feathers. All three of these species build domed nests in order to shelter the brooding bird, and later the young, from wind and rain.

The golden eagle, largest and most splendid British bird, makes, as is natural, the largest and most substantial nest. One eyrie, built in a Scots pine in the Central Highlands, has been added to through the years until it is now approximately fifteen feet high. When she nests in the old Caledonian Forest, the golden eagle builds her nest almost entirely of fir branches and lines it with fresh green fir shoots and twigs, which are torn from the trees. During the prolonged fledging period of the eaglets, the parent eagles bring from time to time to the eyrie green pine branches and flowering shoots of rowan, or mountain ash. The writer has watched an eagle tearing out heather by the roots and carrying it to the nest after the hatching of the young.

Most birds choose a new nesting site each spring, but this is not by any means the rule. The raven returns year after year to the same nest, which has been tramped almost out of recognition by the feet and the weight of the large brood the previous season. Most pairs of golden eagles have two eyries, and use each alternately. An eyrie before the eaglets have left it becomes fouled by the prey which has lain in it, although the eaglets themselves are cleanly in their habits, and before they eject their excreta are careful to rise and stand with back towards the edge of the nest, so that the excreta, which is semi-liquid and is forcibly ejected, falls to the ground well clear of the eyrie.

A bird occasionally uses the same nest for a second brood the same season. The blackbird has been known to do this and the dipper or water ousel. Some birds use the discarded nests of other species. A long-eared owl may lay in the old nest of a grey or carrion crow. In the Outer Hebrides a merlin has nested in the old nest of a grey crow, built on the ground in long heather and not in a rock, as is usual.

In most species the male shares with the female the building of the nest. The long-tailed tit's nest may take six weeks to complete and during that time both cock and hen make frequent journeys to the nest; they must fly many hundreds of miles during their nest building. The golden eagle sometimes begins to nest as early as January, so that the nest-building period is

WHITETHROAT AND YOUNG

This small bird builds an elaborate nest on or near the ground. The father helps to build the nest but mother feeds the babies.

PATERNAL RESPONSIBILITY

In some birds the fathers help with the job of feeding the young birds. This is especially true of the hawks, which are carnivorous and have a voracious appetite when they are young. A male merlin (right) is shown feeding his young.

sometimes upwards of two months. Compare this with the nesting (if such it can be called) of the lesser tern, who scrapes a small hollow in the sand and lays her eggs there, the hollowing out of the depression taking only a matter of a few minutes.

Colour of Eggs

There is an enormous range in the colour of birds' eggs. Broadly speaking, the birds which lay brightly-coloured eggs are those which nest in concealed sites, where enemies are unable to see the eggs. Owls and doves lay white, unspotted eggs; the redstart and the starling, which nest in holes, lay brilliant blue eggs. Birds which nest in the open, in scant concealment, on the other hand, lay eggs which harmonize closely with their surroundings. The oyster-catcher, which nests on shingle beaches along the coast, and also on the shingle beds of most of the Highland rivers of Scotland, lays eggs which harmonize perfectly with the neighbouring pebbles; indeed, even practised observers sometimes find it hard to see them.

An oyster-catcher does not sit closely but runs off the eggs and across the heather or shingle before the human intruder has come near the place. Even when the eggs are chipping and the small, dusky oyster-catchers are cheeping inside the eggs, or are breaking through so that their bills and heads show, the parents do not betray their anxiety but stand quietly beside the river or shore, as if they had no special interest in the locality. During the mating season, and even after the nesting has begun, oyster-catchers play the game of "follow my leader." The birds, usually in odd numbers, run excitedly backwards and forwards, or in circles, each with head down so that the bill almost touches the ground. During the game—if this it be—a continuous excited high-pitched whistling is maintained. These excited cries are distinct from the oyster-catcher's song, which is interesting because the flight of the bird is then altered (the singer sings in the air).

Normally, the oyster-catcher's flight is fast, the wings being driven rapidly, but during the song the wings are moved no faster than those of a gull. Sometimes the change-over in the speed of the wing beats can be seen when the bird, after flying for a time in the usual manner and in silence, begins his song, which is a double note repeated at regular intervals. The oyster-catcher is not alone in having a distinctive flight for the song. The golden plover when singing mounts high in the air before the

full song is given. The swift falcon-like flight of the plover is then changed to a very slow wing beat. Here again the song is a double whistle, the first in a low key, the second in a higher one. The low note is uttered as the slow downward thrust of the wing is made; the high note as the upward lift of the wing follows. As the two whistles are uttered in a leisurely manner, it will be seen that the upward motion and the downward thrust are made very slowly indeed.

Singing in Flight

More birds sing on the wing than is generally supposed. The blackbird sings as he flies, as does the missel thrush, largest member of Britain's thrush family. The greenfinch is another singer on the wing, the flight during the song being inconsequent and almost swallow-like. The lark is, of course, an almost purely aerial singer, as is the curlew, yet both these birds do on occasion sing on the ground.

When the eggs hatch the song of most birds is less frequent, but in those birds having a second brood this quiet period is not of long duration. Many birds have second, and some third, broods in the course of a season, and thus renew their courtship. The song thrush and the blackbird are among the number which on occasion rear three broods. The house sparrow rears at least three broods in the course of a year, and the ring dove or wood pigeon nests from February and March until late October. But even this bird is not

INCUBATION OF THE EGGS

The mother bird guards the eggs and keeps them warm by her body. From time to time she turns them over. A hen lapwing (or green plover) is shown settling down to brood on her eggs.

OYSTER-CATCHER ON GUARD

The oyster-catcher is shown here in a characteristic attitude, feigning indifference in order to distract the attention of the observer from the nest which is some distance away. The nest is inconspicuous as the eggs harmonize with the surrounding pebbles.

so persistent in its nesting as the rock doves of the Scottish coast, whose eggs or young may be seen in any month of the twelve. The young rock doves are unharmed by snow and frost—the nests are in sea caves and thus are to a certain extent protected against the cold—and even survived one of the most severe spells of January frost and snow in living memory.

It may be said that, broadly speaking, the number of broods of young reared in a season is dependent on the length of the incubation period. Birds with a prolonged incubation period have usually one brood. The fulmar, brooding for six or seven weeks, lays only one egg in the year. Indeed, most sea birds are single brooded and most of the great family of waders are single brooded, as are ducks, swans and geese, but ringed plover and woodcock sometimes rear two broods in a season. Most birds lay a second clutch if the first is taken when the eggs are fresh.

Old Nesting Sites

Birds are faithful to old nesting sites. A pair of oyster-catchers have to the writer's knowledge nested in the same part of a small shingle bed on a Highland sea loch for the best part of twenty years. A pair of eagles may nest in the same tree or the same cliff for fifty or a hundred years. In Highland tradition, the eagle is the longest-lived among birds and greatly exceeds the life span of man. It is difficult to prove or disprove this belief, but two instances have been recorded to show the age reached by an eagle. One is the sea eagle previously mentioned, which in a zoo laid its first egg at the age of ninety, the other is of an eagle shot with a gold collar round its neck bearing a date ninety-five years earlier.

It is broadly true that the more slowly a bird becomes mature the longer it lives. The gannet is five years old before it is mature, and thus takes approximately the same number of years to develop as the eagle. There are no records to show the age reached by a gannet, but the inference is that it is great. The widely practised ringing of birds may in time provide valuable information on a bird's life.

The variation in the incubation period in the bird world is great. Broadly speaking, the larger birds have the more prolonged incubation period, but there are exceptions, and the storm petrel, a sea bird scarcely larger than a swallow, broods its one small,

glossy, white egg for six weeks before it hatches it.

It seems also to be a broad rule that the longer the incubation the longer the fledging period. The young swallow is fledged in three weeks; the young storm petrel takes nine weeks in the fledging. Both swallow and storm petrel have helpless young when first the eggs are hatched. How different are the young of the red grouse and the ptarmigan. Young ptarmigan especially are most active on the first day; they lead a free existence, and run far from the nest, to which they do not again return.

The world would be a different place without its birds, for they add life and colour to the earth, and their music adds pleasure to the life of men.

Sex Instinct in Mammals

Among the more highly-constituted mammals, the sex instinct as a general rule finds much less poetic expression. On the other hand, as we ascend the animal scale we find a greater tendency to make love, as man does, in secret.

Voice plays an important part in animal courtship, but not always in sounds which bring pleasure to the human ear, at any rate; for instance, the miaowing of cats at midnight or the bellowing of stags in the autumn. Some animals are practically silent except in the mating season, while others have their vocal organs greatly augmented by special devices at that time.

When one finds an animal has some curious and at first unaccountable habit, it generally proves to have some bearing on sex, possibly a method of advertising, designed to bring the sexes together. Some of their advertising or telegraphic systems are very interesting. As the mating season approaches, most of the weasels have their musking places, where they leave the strong aroma from their musk glands by rubbing these glands on any convenient object, a stump of wood, a branch, a stone or, in captivity, their food vessels may be used. Both sexes practise this, and it is probably the most usual method of advertising among the musk bearers.

The cats and dogs leave their scent in a slightly different way, but again by frequenting those places where others of their kind (if not of their sex) are likely to pass—at the cross-roads of life, so to speak. The wolf of the prairies knows well that if there is the skeleton of an ox or a horse lying about, any wolf passing that way is certain to visit it, so there he leaves his sign. The wild cats usually follow the small game paths, and are fond of leaving their messages on a log crossing a stream, knowing the weakness of their own kind for log-walking—a habit which often exposes them to the wiles of the trapper.

Beavers and otters have much the same ways of advertising. A restless young beaver will run up a river, decide where he is going to build his dam, and probably start it. Thus, having staked his claim, he goes back to the main waterway and leaves his signs at the junction, which other young wanderers are sure to pass, and any other beaver knows that there is one of his own kind at work up the water. So up it goes to have a look round. It may be another young male, in which case they join forces and get ahead with the important work of building. More signs are put out, and it is thus that beaver villages and cities are formed.

Every spring the mud (or sand) pies of the otter can be seen at certain frequented places on every loch and river the otters inhabit. They can be found at roughly the same points year after year, most frequently where a dead tree lies across a stream, thus blocking the straight line of progress. The mud pies look rather as though a child has been playing there, but on the top of each the otter leaves his sign.

Tree-marking Habit

The bears have a peculiar habit. They register their topmost reach on the tree trunks by raking them with their claws, generally using their fangs too, and numbers of trees are to be seen deeply scored. As the tree grows upwards the marks are apt to create an exaggerated idea as to the size of the bears living, or which have lived, in that locality!

Foxes behave much the same as the other canines, but their love affairs are more

DISTENSIBLE VOCAL ORGAN

In the upper picture a toad is emerging from its hole and in the lower picture the same animal is shown with the throat sac distended. The movements of this sac cause the croaking noises which are so noticeable during the mating season of these creatures.

amusing. Fights are common among the males, and are frequently heard, though not so frequently seen, as they occur mainly at night time. A lovelorn vixen seeking a male lets fly a terrible squall, which has often severely scared people. Any dog fox hearing it naturally gravitates in that direction, so that where foxes are numerous the lady may find herself surrounded by a whole party of admirers. Coyly she moves away, and the whole male rabble follows at her heels, snarling and grimacing at each other. Should one of them become too impertinent, she whirls round and bites him, then all the others bite him, and soon finish up by all biting each other, till a veritable scrimmage is formed. By the time they have sorted themselves out, the vixen is probably out of sight.

Monogamy Among Animals

Some animals marry in the true sense, male and female sticking together and guarding their young mutually, and there is no doubt that the majority of birds are monogamous. A few, like the cuckoo, and some of the more brilliant game birds, are the exceptions.

The fox is really monogamous, though he goes astray a good many times. All monogamous animals do. We must not compare their morals with our own. The most faithful fox father, carrying food for his vixen and watching over his young, is bound to trip up if the opportunity occurs. In fact, they are all opportunists.

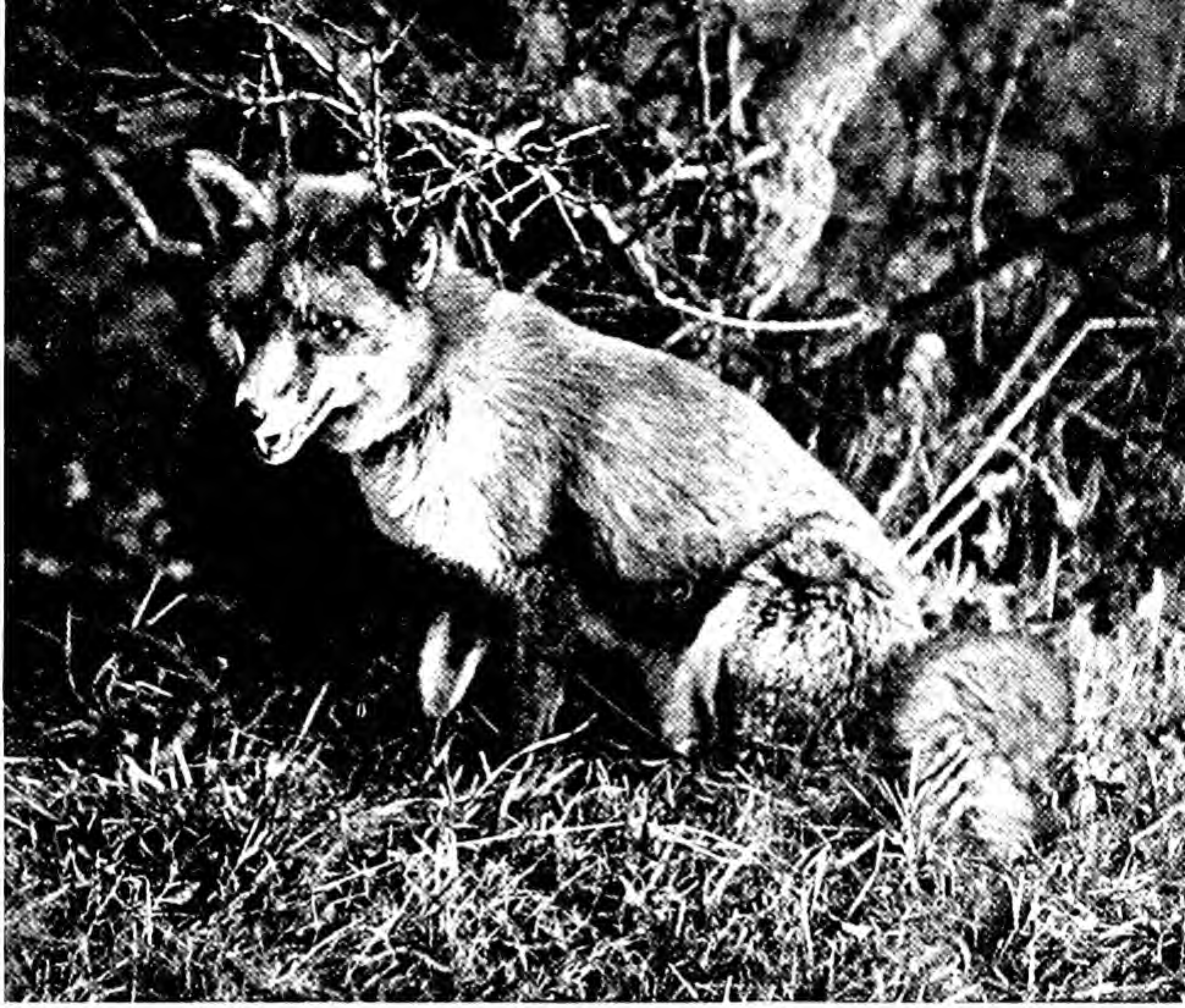
So far as one can judge, badgers are more faithful to the laws of monogamy than are foxes, but they spend so much of their lives underground and are so strictly nocturnal that they are not so easy to learn about.

Very early in the spring, the old dog badgers begin to wander about the hillsides, cleaning up the earths and leaving immense heaps of soil or sand at the burrow entrances. This is the first indication of the mating season, and the badgers in high mountains certainly travel great distances as winter tails off. Their unmistakable, bear-like tracks are to be seen crossing every snowdrift, and so from one mountain cairn to another in search of their mates.

Wild cattle can be described as clannish rather than monogamous. The families stick together, generally led by some old grandmother of the clan. One can see the family likeness running through them. Often these old grandmothers are so beloved by their children and their children's children that their coats acquire a curly and silken texture through one or another of the herd constantly licking them. When a calf is

RIVER DWELLER SEEKS A MATE

Otters nest in burrows in the banks of rivers and the young are born there. The males leave little heaps of sand or mud near their dwellings and these signs help them to find mates.



FOX'S MATING CALL

Foxes nest in burrows or "earths" and bear their young there. If a female fox perceives a male during the mating season she gives a cry which often attracts other males also to her.

born the bulls will gather round it in an iron ring, heads outwards, to protect it and its mother from the meandering wild dogs, or whatever the enemies may be. It would seem that generally the wild cattle have an intense affection for each other, but one cannot say that they are monogamous, any more than are the domestic cattle of our fields.

The majority of the weasels are polygamous, and so are most of the smaller cats. If stoat meets stoat, or weasel meets weasel, it is generally either a love affair or a fight to a finish. The male definitely does not participate in the upbringing of the young. Cats mate only for a brief period, then again the male goes off. It would appear that this applies to the leopard and the tiger, but the more dog-like lion, on the other hand, sticks to his mate and his cubs, and certainly plays a part in the upbringing of the young—unless he gets angry and decides to eat them. This may happen in the best of wild homes.

So far as the females are concerned, the most gentle and faithful are often among the savagest; the mother wolverine, for example, the ferocity of which was referred to in a previous chapter, is an exemplary mother. She will face fire and water, even man, in defence of her family. Most of the rats are polygamous, most of the mice at least live in pairs, as do squirrels.

So we go on up and down the scale, generally finding that those which live the best home lives are most attractive to ourselves, and are best able to maintain their footing on a level standard.

We come now to those animals, mostly the split-hoofed animals, the deer, the sheep, the goats, and so on, which have their regular mating seasons, which we call their rutting seasons, most of them in the autumn. At other times of the year

RED DEER'S CHALLENGE

A male red deer challenging another to fight during the mating season. The females of the species tend to mate with the winners of these fights.

Though various deer have been introduced into Great Britain from Japan and elsewhere, the three indigenous deer are the red deer (stag) of the Scottish Highlands, Exmoor, the New Forest and a few other places (these are the biggest); the fallow deer, herds of which run wild in various places from Dunkeld in Perthshire to Hampshire (this is the parkland deer with the palmated antlers), and last but by no means least, the clever little woodland roe with his upright dagger horns, distributed all over Scotland and fairly plentiful in the wilder parts of England, particularly the Lake District. It should be noted that with the largest deer (moose, sambur, wapiti, caribou, and a few others) the parents and young are designated cow, bull and calf. With the red deer they are stag, hind and calf, while with the smallest deer (and they are dotted all over the world) the names are invariably buck, doe and fawn. These names should be memorized, because it is quite incorrect to speak of a red deer calf as a fawn, and so on.

Of the three deer, red, fallow and roe, the red and the fallow are decidedly polygamous, and they are gregarious in their habits. The little roe are given more to living in families, say, father, mother and the female fawns of the past three years or so, and though they often separate in autumn, the bucks seeking the misty swamp lands and lake margins, the does making for the higher woodland, there is every indication that the families re-unite when food conditions in the woods make life easier. The mating season of the roe is about August; the roaring or rutting season of the red deer generally begins in late

they wander hither and thither, controlled by food supplies. In spring and early summer the females go into retirement and devote themselves to their young. Most species have their appointed breeding slopes, which catch the sun and are sheltered from the wind and reasonably secure from their enemies. Often, the males entirely segregate themselves from the females at this time of the year, living their bachelor lives along different ranges. So in the Rockies we have sheep country and ram country; and in the Scottish Highlands we have stag country and hind country.

With the giant moose of Canada, much the same thing occurs. The bulls seek the high ranges as the snows begin to deepen, the cows seek the sheltered valleys, and remain there in seclusion till the following autumn. So sedentary do the cows become, accompanied by their calves, that often their hoofs spread and curl upwards like sabots, and by this grotesque overgrowth hunters can easily distinguish the tracks of the cows when the hunting season arrives.

September or early October, according to the weather—early frost precipitates the rut. Practically all the true deer the world over shed their horns annually..

The red deer are certainly most interesting during the rutting season, when the big stags come down to join the hinds. Hitherto, they have lived almost the quiet lives of cattle, but in a single night all that is changed. One evening, the first harsh grunting and rumbling of a stag is heard. The rutting season has begun. A night or two later, the slopes and corries ring with the wildest music in nature—the roaring, rasping and bellowing of the stags, which have become hump-backed and swollen in the neck. From that day on, generally till the first deep snows, the forests remain in a turmoil, filled with the rumbling of hoofs as the red-eyed master stags sort out their claims, and the barking of the herded hinds driven hither and thither by their masters. At the commencement of the season they soon sort themselves out into herds, each master stag with his parcel of hinds appropriating his own terrace, while the less able beasts prowl restlessly hither and thither, trying to break up the herds and adding generally to the din.

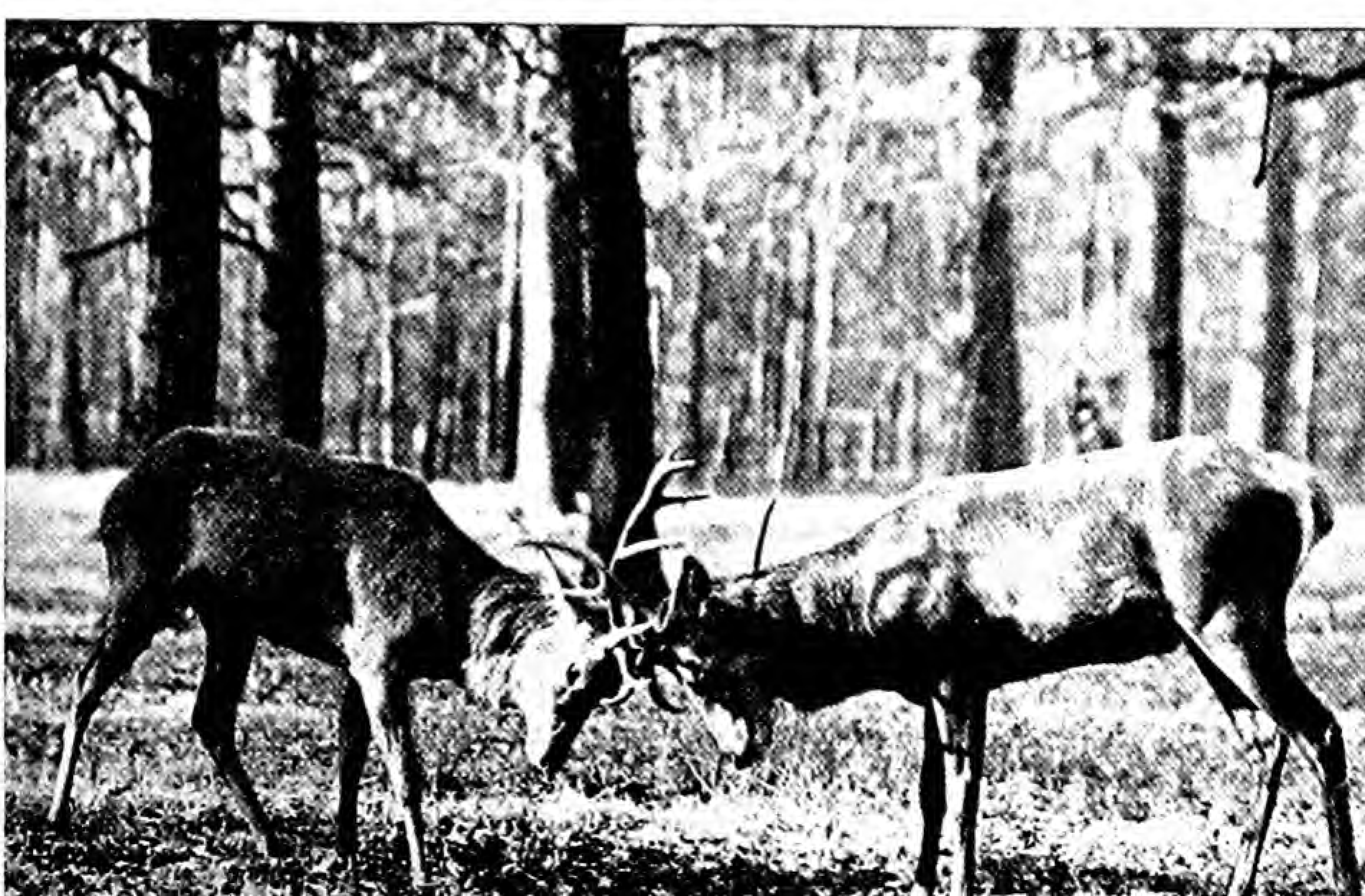
But the greatest activity is at night time, when the deer begin to wander towards the lower slopes by their ancient pathways. Here and there a stag dashes in; herd joins herd, the master stags marshalling and trying to keep their wives together, but it is hopeless.

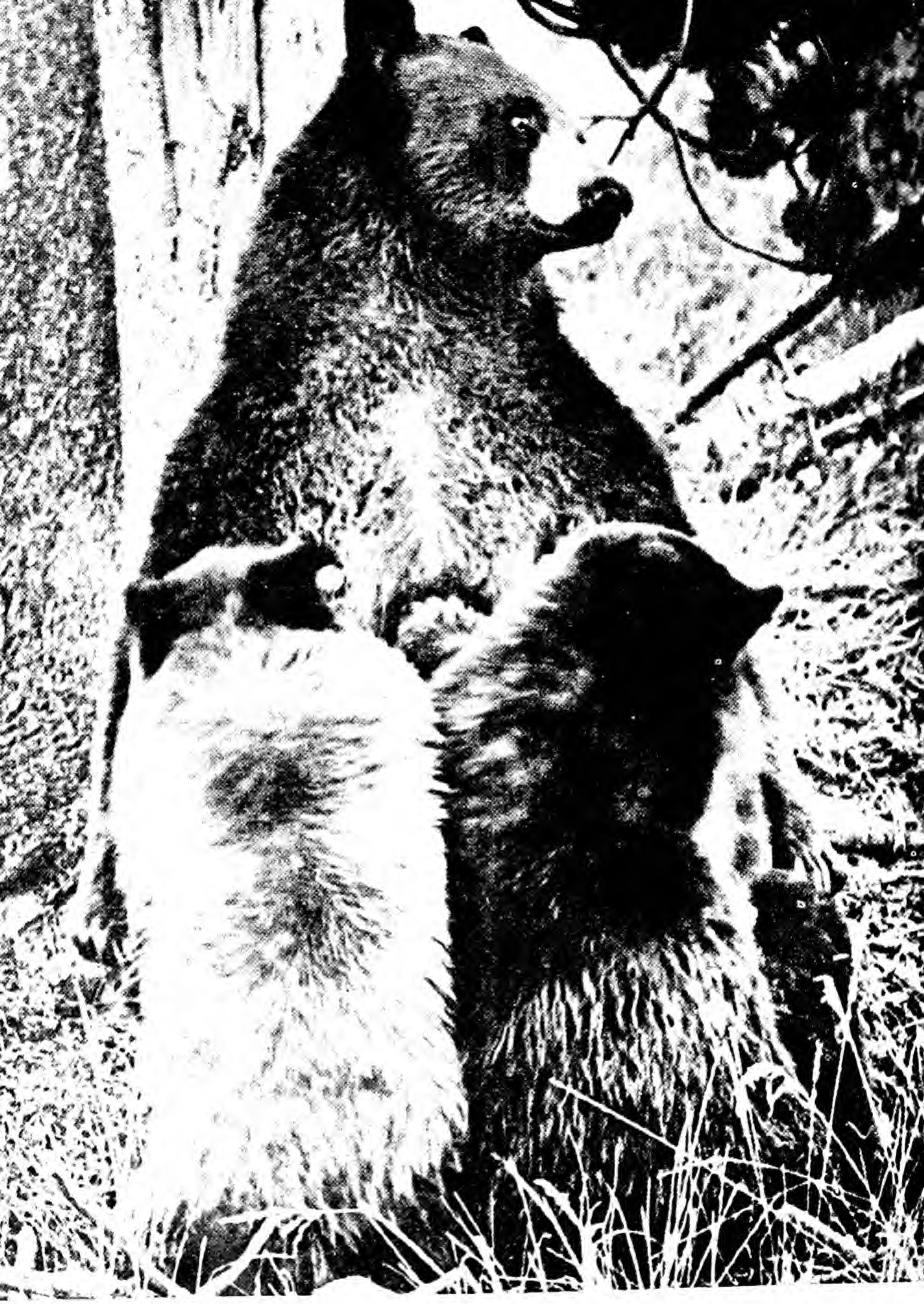
Real fights do not occur until a little later in the season, for the king stags take care not to face each other, while the weaker beasts dare not face them. But for a time these masters of the forest get little chance of eating, and even less of sleeping. They weaken rapidly, until the day comes when a watching rival sees his chance, and they lock antlers. Then another change comes with surprising suddenness. Almost in a day, the old monarchs are driven out, and the herds of hinds are under different masters. After this the old fellows, sick and out at elbows with their lot, seek the high corries, generally in twos and threes, to live as close comrades, all their differences forgotten.

Another curious way in which the little

CHALLENGE ACCEPTED

Duel between two red deer during the mating season. Tremendous battles take place over the females who are rounded up in herds by the stags. When a younger rival challenges a master stag, the battle starts by their locking antlers.





BLACK BEAR WITH CUBS

The young of hibernating bears are born while the mother is passing the winter in her lair beneath the snows. They are born at a relatively early stage of development and remain attached to their mother's breast while their development is completed.

roe deer differ from the rest, is that, though they mate in August, and the much larger red deer mate in October, the calves of the one and the fawns of the other are born about May. In fact, there is no development of the foetus of the roe until well on into the winter, after which the calf matures as with other animals.

As a rule, the periods of gestation in animals are proportionally the same according to their size, but there are a few more curious exceptions. The sow badger seems to have the exceptional gift of postponing parturition if she so desires. For example, if she is taken into captivity already pregnant she may not part with her young for a year or even two years after the appropriate time.

Otters normally carry their young about nine weeks, but curiously enough their eyes do not open, nor do they obtain their full hearing, until about six weeks old, instead of say, twelve days, as is normal for creatures of their size.

The young of the giant grizzly are born deep under the snows while their mother is hibernating, and on their arrival they are in an abnormally undeveloped state, no bigger than newly born terrier puppies. Each attaches itself to its mother's breast and remains attached for several weeks, slowly gaining in strength until by the time the snow is gone their eyes are open and they are ready to emerge in gentle stages. Thus it will be seen that the grizzly gives birth to her young at a much earlier stage of development than other animals, then nourishes them externally instead of internally. Millions of years have brought about this order of things by the animal's habit of giving birth to its young when dormant deep under the shelter of the snow.

Gregarious Animals

There are some animals which seem to fall between the monogamous and the polygamous. They are gregarious and, on the whole, the males are ever ready to defend the females and the young, though they do not stick to any individual mate. Among these, the father generally recognizes his own young. It is not uncommon to see a stag followed closely as a shadow by one of his own stag calves, which he licks and caresses, but he would not for a moment tolerate the company of a calf not of his own blood. The same applies to cattle.

In most cases, the fur-bearing animals mate in the spring, but most of the cloven-hoofed animals mate in the autumn. There is considerable elasticity in all this. Taking the weasels—the stoat generally produces only one litter per year; his nearest relative, the little weasel, produces litters and keeps on producing them except in dead of winter, while the much larger otter follows the example of the tiny weasel instead of the larger stoat. So it becomes evident how impossible it is to generalize or to try to fix anything in nature on the basis of rules. And again, a season of super-abundance or of abnormal scarcity may upset the whole normal order of things.

Test Yourself

1. What are the ways in which simple animals reproduce? Give examples.
2. Do you find asexual reproduction in the higher forms of life?
3. What is meant by regeneration? Is this means of reproduction of special value to organisms in survival?
4. What is a hermaphrodite? Give examples of parthenogenesis.
5. Compare the chances of survival of a young corncrake and a young fulmar petrel.
6. Can you suggest why some birds lay their eggs on the ground or on crude nests, whereas others build substantial nests in trees or sheltered places?
7. Explain the principle of reproduction in the higher animals.

Answers will be found at the end of the book.

BEE VISITING BLEEDING HEART

Pollination by means of insects is one of the most common as well as the most efficient methods. The bee is attracted by the bright red, heart-shaped flowers, and as she has to push her way well into the flower to get the nectar, fertilization is virtually assured.

CHAPTER XI

REPRODUCTION IN PLANTS

REPRODUCTION among plants, as among animals, in its simplest and most primitive form may be regarded as one of the obvious results of growth. The process, however, is not a simple one. When a unicellular plant, such as a bacterium, or one of the Blue-green Algae, has attained a certain size, its protoplasm ceases to grow. The little plant then divides into two equal halves which separate from each other as two new and independent individuals. Nothing is left of the original organism, it has simply split up into two smaller ones, and each of these in turn, on attaining a definite size, will split in half.

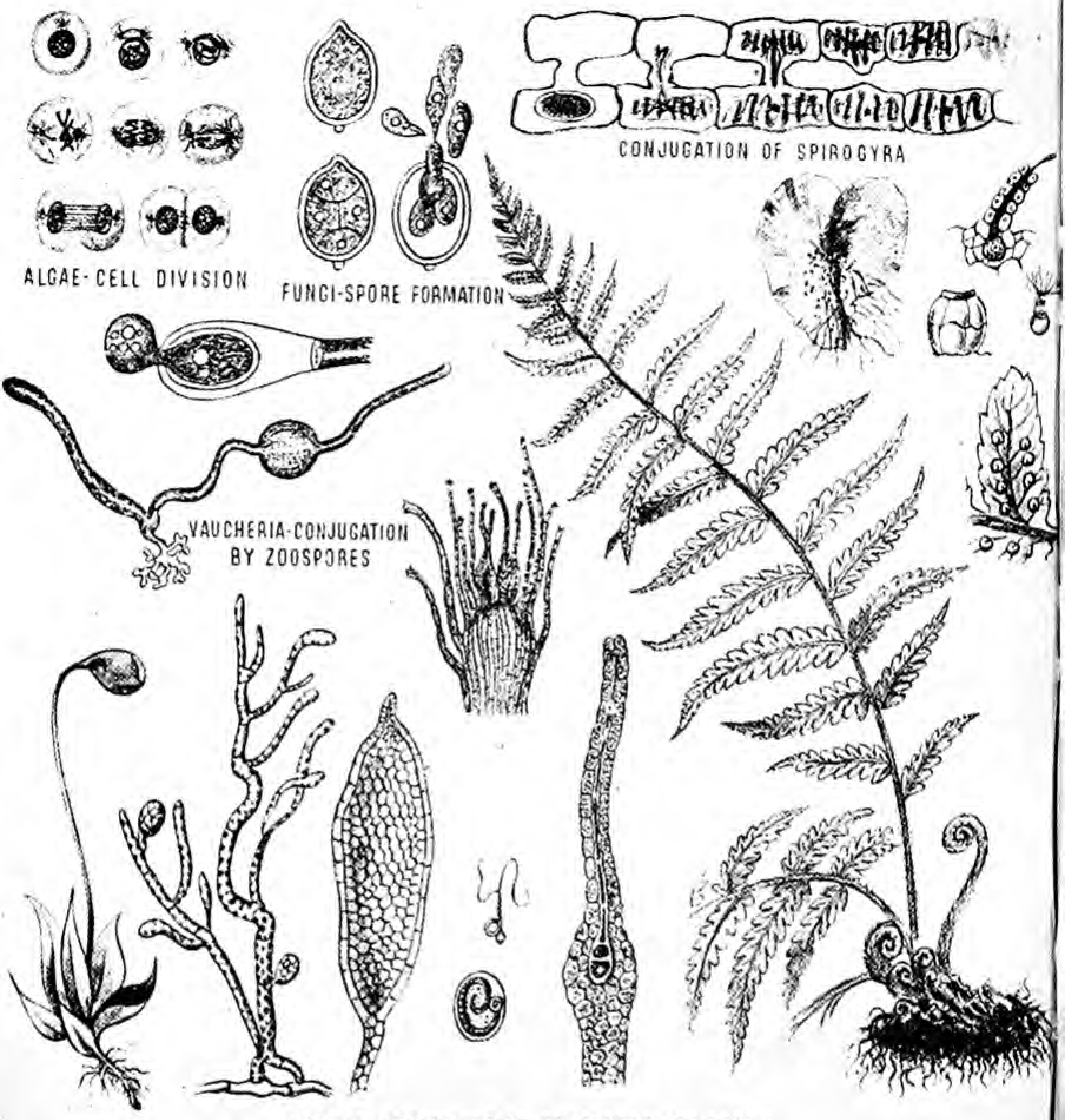
What has happened is that at first nutrition has enabled growth to proceed and has prepared the way for, and then given way to, a fresh set of chemical processes which bring about the cleavage of the organism into two smaller parts. The whole process, as most often encountered in nature, is more or less intimately connected with an abundant supply of nutrition.

The rapidity with which many of these very simple unicellular plants can multiply, provided nutrition conditions are suitable, is truly amazing, particularly among the bacteria, in which a colony often doubles its numbers every fifteen or twenty minutes. Imagine what that means. In about twelve hours, one single individual bacterium might well give rise to close upon seventy thousand individuals. Fortunately, under natural conditions, it is highly improbable that anything like this number is ever actually reached, for as such a colony begins to grow the individuals begin to compete with each other for the available food supply. Moreover, in the process of active growth and division, certain poisonous waste products are given off. These two factors act as a check on the rate of multiplication and ultimately may lead to the extinction of the colony. But before this can happen, a certain proportion of the individuals, instead of splitting in half, may develop a more resistant cell wall, and become what are known as resting spores. Thus, the species is preserved from complete extinction, and the individual spore survives until a return of suitable nutritional conditions enables it to resume active growth and division. In many bacteria, these resting spores are resistant to desiccation and to very high temperatures, rendering complete sterilization of contaminated articles extremely difficult.

Water Bloom

In the simple Blue-green Algae, reproduction takes place in the same way, by division of the individual. Given suitable climatic and nutritional conditions, multiplication may be very rapid and responsible for what is known as water bloom, caused by the sudden appearance of vast numbers in ponds and lakes, covering the entire surface with a bluish-green scum. In *Nostoc*, a filamentous form, the threads are associated in colonies held together by the soft gelatinous walls of the individual cells. These colonies often form conspicuous masses of bluish-green jelly on damp ground during wet weather, and the tiny individual cells of which each thread is composed, when revealed by the aid of a microscope, present a rounded bead-like appearance. The interior of each cell is full of protoplasm, which appears to be coloured greenish-blue throughout its whole mass and to be destitute of any chlorophyll bodies.

In *Nostoc* each filament can be seen to be interrupted at intervals by larger oval cells with thicker walls. At times the filament breaks across at these points in the chain, so that the short rows of smaller cells between them become isolated, escape from the gelatinous mass, and give rise to new colonies. Another mode of reproduction in *Nostoc*, propagation perhaps would be a more correct term, is by means of resting

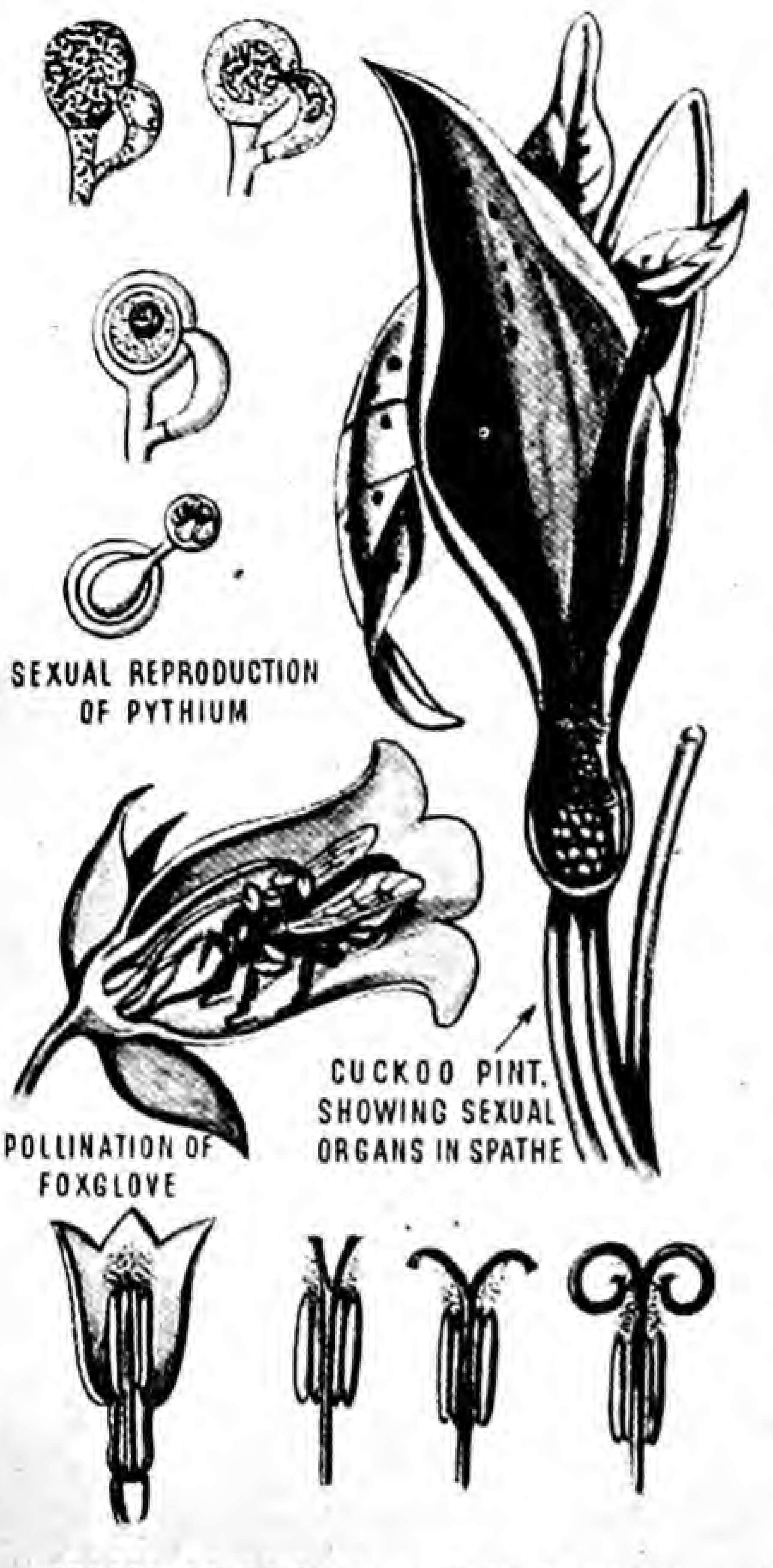


SEXUAL REPRODUCTION OF MOSSES AND FERNS

spores formed directly from the vegetative cells, which in this circumstance grow larger than the rest, accumulate abundant protoplasm, and surround themselves with a thick cell wall. This enables them to pass through a resting stage and to endure drought. On the return of moist conditions in the surrounding soil, they germinate and form new filaments.

The next step can be conveniently observed in *Spirogyra*, a green filamentous fresh-water alga common in ponds, where it floats, often in large masses, near the surface. Its filaments are perfectly free, having no attachment to any substratum, or differentiation into apex and base, all the cells composing the filament being exactly alike. Though under ordinary conditions the plant is multicellular in form, sometimes the filament breaks up into its separate cells, each capable of leading an independent life and starting a new filament. Physiologically, *Spirogyra* may be regarded as a unicellular plant, all its cells being equivalent, each cell appearing capable of carrying on all the necessary functions for itself.

In *Spirogyra*, the division of the cell coincides with that of the nucleus, which takes place by a complicated process very



HOW PLANTS MULTIPLY

Our drawing illustrates some of the many methods by which plants reproduce themselves. Cell division is the simplest form. Flowering plants reproduce by means of seeds.

similar to that seen in the higher plants, and which results in the formation of two exactly identical daughter-nuclei. While the division of the nucleus is in progress, a transverse membrane, termed a septum, gradually grows inward from the sides of the cell wall until a complete partition is formed dividing the cell and its contents into two equal parts, each containing one of the newly formed daughter-nuclei.

This mode of cell division and increase is common among all the lower plants. The breaking up of the *Spirogyra* filament into its component cells may be regarded as an asexual means of propagation.

Normal reproduction in *Spirogyra*, however, is always sexual, and is a form of conjugation consisting in the union of two similar cells. It usually takes place between two filaments that are lying closely side by side. The cells of each filament develop lateral tubular outgrowths which exactly correspond to each other in position, and on coming into contact adhere together. The walls separating them are then absorbed, leaving an open tunnel-like passage between the opposite cells of the two threads, which thus joined look like a miniature ladder.

Cell Contents Contract

Meanwhile, the contents of each cell in one of the filaments have contracted from the cell wall so as to form a free, more or less rounded mass. The contents of the cells of the other filament, however, for the time being, remain unchanged. The contracted cell contents next begin to pass into the tubular connecting passage, through which they gradually push their way into the opposite cell, and there ultimately unite with the contents of the latter, which in the meantime have contracted from their cell walls.

As a result of this union, there is a fusion of the nuclei of the two conjugating cells. The united protoplasmic mass takes on a rounded or oval form, and surrounds itself with a cell wall which ultimately becomes thickened and cuticularized on its outer surface, and becomes a resting spore, capable of withstanding a period of drought, or the cold of winter. That a certain distinction of sex is present in *Spirogyra* seems evident from the fact that all the cells of each conjugating filament usually behave in the same way, either giving up their own protoplasm or receiving that of the neighbour filament. However, that the difference has not yet become a

CONJUGATING FILAMENTS OF SPIROGYRA

Photomicrograph of filaments of Spirogyra showing stages in lateral conjugation. Each two uniting cells form a zygospore.

fixed one, is shown by the fact that sometimes, particularly in a filament that has become isolated, conjugation will take place between adjoining cells.

In such circumstances, two adjoining cells will each put forth a short lateral tube, close together, on either side of the transverse wall separating the two cells, and the contents of one cell will pass through the side tubular passage to unite with those of its neighbour.

In *Spirogyra* is seen in its simplest form what really is the type of all sexual reproduction, which consists essentially in the fusion of two distinct cells accompanied by the union of their nuclei. Those structural differences which we shall find developed between male and female cells in the higher plants, must be regarded really as of secondary importance, as special adaptations to secure their union by the least possible expenditure of material and energy. Conjugation, as seen in this relatively simple aquatic plant, may in fact be regarded as the primitive form of fertilization.

We will take as our next example *Vaucheria*, a member of a group of green algae, which differ profoundly from *Spirogyra* in their general structure and sexual character. *Vaucheria* occurs commonly in fresh water or on damp soil. It consists, in the vegetative condition, of a cylindrical green filament, repeatedly branched at irregular intervals, and is attached to the substratum by a colourless root or rhizoid. The contents are uniform throughout the green part of the plant, for at first though more or less branched, no transverse dividing walls exist. Thus, the entire filament consists of a single cell enclosing a continuous protoplasmic body in which numerous nuclei and small green chloroplasts are embedded. Only the reproductive organs, when formed, become divided off from the main plant body by transverse walls or septa.

Two Kinds of Cells

In *Vaucheria*, reproductive cells of two kinds are produced, asexual and sexual; asexual reproduction affording a rapid means of propagation and taking place chiefly when the plant is growing in abundance of water and under generally favourable conditions. In a plant undergoing asexual propagation, the protoplasm accumulates and becomes denser at the end of a branch, which in consequence assumes a club-shaped form. The enlarged end next becomes separated from the rest of the filament by a transverse septum to form what is termed a spore-capsule or zoosporangium, the entire contents of which go to form a single large motile spore clothed over its whole surface with numerous short cilia. This zoospore, as it is called, contains a number of nuclei and chloroplasts. The numerous cilia are in pairs, each pair corresponding with a nucleus; so obviously *Vaucheria's* large active spore really corresponds to a multitude of small spores which have not become separated from each other.

In most other species of *Siphonacae*,

numerous active spores, usually with two cilia each, are formed in the sporangium. The escape of the single large motile spore of *Vaucheria* usually takes place in the morning, and the spore is sufficiently large for its movements to be observed with the naked eye. After swimming about in the water slowly for a short time—for a quarter of an hour or longer—it comes to rest and immediately withdraws its cilia, and germinates at once, sending out a filament which attaches itself to the soil by a colourless rhizoid, and soon begins to branch.

Development of Sexual Cells

This asexual mode of propagation may continue indefinitely, generation after generation, so long as climatic conditions and abundant water supply remain favourable. But should conditions change, and particularly danger of drought threaten, the *Vaucheria* immediately responds by the formation of sexual reproductive bodies. These first appear as small protruberances which grow out into short lateral branches and become separated by transverse walls from the rest of the thallus, and ultimately develop female cells called oogonia, and antheridia or male bodies. The female cell in its mature condition fills the knob-shaped apex of the branch, which has a beak-like projection at one side. A small secondary outgrowth below contains the numerous male cells, and on maturing usually curves downward like a short blunt horn. Its base is cut off from the rest of the thallus by a transverse wall so that it becomes a true male recepticle or antheridium, the equivalent of the male organ, or anther, of the higher flowering plants.

The more central portion of this antheridium now breaks up into extremely minute cells or spermatozoids, each possessing a single nucleus, and externally two cilia inserted on one side. These ciliated cells begin to swarm within the antheridium, which now opens at its apex, and expels them together with a portion of the unchanged protoplasm. In the meantime, developmental changes have taken place within the female egg-cell. A portion of the original protoplasmic contents has wandered back into the filament, taking with it all the nuclei except one, so that the egg-cell has become a single nucleate cell, the outer wall of which has formed a small receptive spot or papilla. The contents of the oogonium next rearrange themselves so that the portion towards the papilla becomes free from chloroplasts. The wall of the cell opens at this receptive spot, and at the same moment a portion of the colourless protoplasm is extruded. Fertilization now takes place. The spermatozoids collect round the receptive spot of the egg cell, into which one spermatozoid finally penetrates.

After the egg cell has been fertilized by the fusion of its nucleus with that of the spermatozoid, it surrounds itself with a cell wall of some thickness, and passes into a resting stage. It has become a resting spore capable of enduring a period of drought with safety. On the return of sufficient moisture germination takes place; the resting spore giving rise directly to a new *Vaucheria* plant.

Thus, sexual and asexual reproduction may both occur in the same individual filament, and on the external conditions of the environment depends whether the one or the other form of propagation takes place. In the sexual form, fertilization in *Vaucheria* demonstrates precisely the same process as occurs in the higher plants, the union of the nuclei of two cells of opposite sex. As we shall learn, the means by which sexual reproduction is brought about varies greatly in the different divisions of the plant world, and according to the natural habit and environment of the plant; but the result is the same always, that is to say, the union of the nuclei of a male and a female cell.

Destructive Fungus

As our first example of one of the higher fungi, we will take a common and relatively simple form which is of economic interest on account of the great havoc it can cause under favourable conditions to seedlings. At the same time it is of scientific interest because it shows an undoubted affinity with the alga *Vaucheria* whose methods of reproduction have been described above.

This fungus is parasitic in habit, and is known as *Pythium*, and can be obtained almost with certainty by growing cress seedlings under a bell glass, and giving them an excessive supply of water. In its vegetative condition, this fungus consists of long, irregularly branched filaments, or hyphae, which is the name given to the filaments of fungi in general.

It is usual to speak of the whole vegetative thallus of a fungus as the mycelium. In *Pythium*, the mycelium penetrates the tissues of the seedling host and spends most of its vegetative life within them. The whole of the host plant becomes infected, and is traversed throughout by the branches, or hyphae, of the parasite.

Formation of Sporangia

Those hyphae of *Pythium* which are to produce the asexual organs of reproduction, grow out into the open air where they form a number of spherical spore cases called sporangia, which are terminal, being formed either on the ends of short branches, or of the main hyphae. These sporangia are beaked at their apex, and, when ripe, the whole protoplasm passes out into this beak which swells up into a bladder-shaped sac. This process can take place only when sufficient water is present entirely to cover the sporangia. The contents of the spore-case then divide up into a number of cells which ultimately become motile spores each bearing two cilia. On the rupture of the spore-case, these motile spores make their escape and swim away through the surrounding water. Eventually they come to rest and germinate, thus producing a hypha which finds its way into a fresh seedling host as soon as an opportunity occurs.

This mode of reproduction is obviously identical with that of an alga, and shows that though *Pythium* is a fungus, it has not become thoroughly adapted for growth on dry land; for its normal method of reproduction can only take place under water. It is the presence of an excess of water alone which enables *Pythium* to spread, and that is why seedlings attacked by it are said to damp off. A provision against an insufficiency of water to float these active spores exists, and under such conditions the sporangium, instead of forming zoospores, grows out into a hypha, thus starting as a new plant capable of invading a fresh seedling. Moreover, *Pythium* can live for a time as a saprophyte on any decaying matter in moist surroundings.

Sexual Organs of Pythium

Sexual reproduction in *Pythium* is brought about by the formation of male and female organs (antheridia and oogonia) either within the tissues of the seedling host, or on hyphae which have grown out into the air. There is, however, no division of the contents of the male organ into spermatozoids. The bulk of the protoplasmic content passes out through a short tubular outgrowth of the male organ that has penetrated the wall of the egg-cell, and united with the protoplasm of the ovum. Spermatozoids are rare among the higher fungi, their complete adaptation to a terrestrial life having involved the disappearance of motile active reproductive cells.

As a result of fertilization, the ovum of *Pythium* surrounds itself with a thick cell wall and becomes a resting spore, germination taking place after a long quiescent interval, and then only when it is brought into contact with water. The sexual reproduction in this fungus is, in fact, a provision to tide over adverse environmental conditions, failure of food supply and water, when active normal vegetative growth and propagation cannot go on.

Rust and Mildew

As an example of a higher and more complex fungus, we will take *Puccinia graminis*, a typical parasitic form that has become adapted exclusively to life at the expense of other plants, and which causes the well-known diseases called rust and mildew in wheat and other cereals. For the complete development of its life-cycle, however, *Puccinia* requires two absolutely different host plants; the second being the common barberry. What is known as the rust stage occurs commonly during the summer on the leaves of wheat, oats, rye, and various wild grasses. Conspicuous long, rusty-red or orange streaks are formed between the leaf-veins, or on the

surface of the stem of the host plant, representing the fructification of the fungus.

These rusty-coloured streaks are made up of a fine powder consisting of spores called uredospores. The latter name is retained as having originally been used when they were regarded as the spores belonging to a different species (*Uredo*), now known as merely representing a particular form of fructification of *Puccinia*. These uredospores when mature are scattered by the wind, and on coming into contact with another wheat plant or other grass family host, germinate, the hyphae growing along the surface of the leaf of the host plant until a stoma is reached, through which entrance to the intercellular spaces of the host is effected. Thenceforth the hyphae develop a new mycelium, from which fresh crops of spores arise, and thus asexually, throughout the summer, rapid propagation and spreading is carried on.

Resting Spores

Later in the year, however, another kind of spore, borne on the same mycelium as the uredospores, begins to appear, the external sign of what is taking place being a change of colour from rusty or orange-red to dark brown or black. This is the stage in the life-cycle of *Puccinia* when it is popularly known as mildew of wheat and other cereals. These black spores are known as teleutospores, and are quite different in structure from the summer spores, being surrounded by an excessively thick cell wall. In fact, they are resting spores which will not germinate until the following spring, and they complete the stage in the life-cycle of the fungus so far as it is associated with wheat or any other member of the grass family.

With the return of spring, these winter spores germinate, but their hyphae never develop into a normal mycelium, being strictly limited in growth. They form what is technically known as a pro-mycelium, which divides by transverse walls, cutting off usually a row of some four cells from its terminal portion. Each of these cells then sends out a slender lateral outgrowth which swells out at its end to form a small spore-like cell or sporidium. Thus the winter spore obviously is incapable of directly reproducing the typical form of *Puccinia*. These spores when ripe are capable of direct germination, but if not carried by the wind to their proper host plant, form only a very short hypha which immediately gives rise to a secondary spore, so as to gain a further chance of successful dissemination.

These spores are incapable of infecting any member of the grass family, being entirely dependent for their future existence upon a totally different host, namely, the common barberry, or some of its allies. Should a spore succeed in reaching the leaf of a barberry bush, however, it at once germinates and sends out a hypha which is capable of penetrating the skin of the leaf and, therefore, has no need to make use of the stomata to affect an entrance into the tissues of its new host. In this respect, it obviously differs from all the other forms of spores produced by *Puccinia*. The resulting fructification is totally different, what are known as cluster-cups or aecidia being formed on the under-surface of the leaf of the infected barberry.

Aecidium Stage

The presence of the fungus growing within the tissues of the barberry is shown by the appearance of swollen, discoloured patches on its leaves during the spring. As the growth of *Puccinia* advances, there appear on the under-side of the infected leaf, on the swollen spot, clusters of small attractive looking golden-yellow cups, filled with minute spores. This is what is known as the aecidium stage in the life-cycle of *Puccinia*, having originally been described under that name as belonging to a distinct genus, just as happened with the *Uredo* stage.

The aecidium cup is formed by a group of hyphae which become densely felted together in an intercellular space of the barberry leaf. It is from the base of this mass that a row of vertically elongated cells arises, the hymenium as it is termed, from which the spores are developed. These aecidiospores are bright yellow in colour and grow at first in parallel chains completely filling the tiny cup, the chains

eventually breaking up into separate spores, which within a few hours of their dispersal can germinate, should sufficient moisture be present.

They are, however, only capable of forming a mycelium, if they have been carried away from the barberry by wind or driving rain, on to the leaves of some wheat plant or other member of the grass family. If that is successfully accomplished, then the spore germinates, sending out a hypha which as it grows bends first one way and then another until its tip finds a stoma. Then the hypha passes through the opening of a stoma into the intercellular spaces of the wheat or grass host, and develops a mycelium from which uredospores are soon produced, thus completing the remarkable asexual life-cycle of this fungus.

Reproduction by Spores

In all the great division of the fungi known as the Basidiomycetes, to which the true mushroom (*Agaricus campestris*) and all the various toadstools belong, only asexual reproduction by spores is definitely known. No evidence of a sexual process at any stage in their development has been established. The cells from which the spores arise are known as basidia, and they are produced in enormous numbers. Some idea of the immense quantity may be demonstrated by carefully cutting off the crown of a mushroom and laying it, gills downward, on a sheet of white paper. If allowed to remain for a time undisturbed, and then gently lifted, an exact print of the gills will be found on the paper, in the form of a fine powdery deposit of basidiospores which has fallen from them.

Alternation of Generations

In the next great division of plants, the Bryophyta, which comprises the liverworts (*Hepaticae*) and mosses (*Musci*), there is a marked advance in structure both of the plant body and the sexual organs. There are always two phases of the plant's life, in each of which it has a different form, each characterized by the production of different reproductive organs. In one phase spores are produced, capable, like those of the algae and fungi, of producing a new plant; giving rise to what is known as the sporophyte, or spore-bearing plant. In the other phase, male and female sexual reproductive cells, are developed, which are not capable of this independent germination, but must fuse in pairs, their union producing an egg cell which is capable of germination. The plant body producing these sexual cells is termed the gametophyte.

Thus, these sexual and asexual methods of reproduction occur in regular and constant succession, in the liverworts and mosses, and exhibit what is known as an alternation of generations.

Funaria

We will take as our example of the Bryophyta the common moss *Funaria hygrometrica*, which usually grows in close, bright green tufts on damp ground, and sometimes on old damp walls. If we separate out from the colony a single plant, we shall find that it consists of a slender stem about half an inch in length, densely clothed with simple leaves. The upper part of the stem terminates in a bud, while at the base of the little plant there grow out a number of fine root-hairs or rhizoids, but no real functioning root, for such an organ does not exist in any of the Bryophyta. Attached to one or more of the rhizoids, a small globular body may be seen, known as a bulbil, which, on separation, grows out to form a much branched filament from which new moss plants arise; actually an additional simple mode of propagation by buds capable of growing into individual plants.

Funaria differs from many other mosses, in bearing the two sexes on different plants. The individual moss plant is the gametophyte, and on it the sexual organs are developed. The plants on which the male organs occur, bear close rosettes of leaves at their apices within which a number of antheridia are developed. When mature, the antheridia are club-shaped bodies, each containing a large number of male gametes or sperms, microscopic in size, spiral in form, with two cilia at one end. The female organs, or archegonia, are borne on plants of smaller size; each being a flask-shaped body with a long neck. Both male and

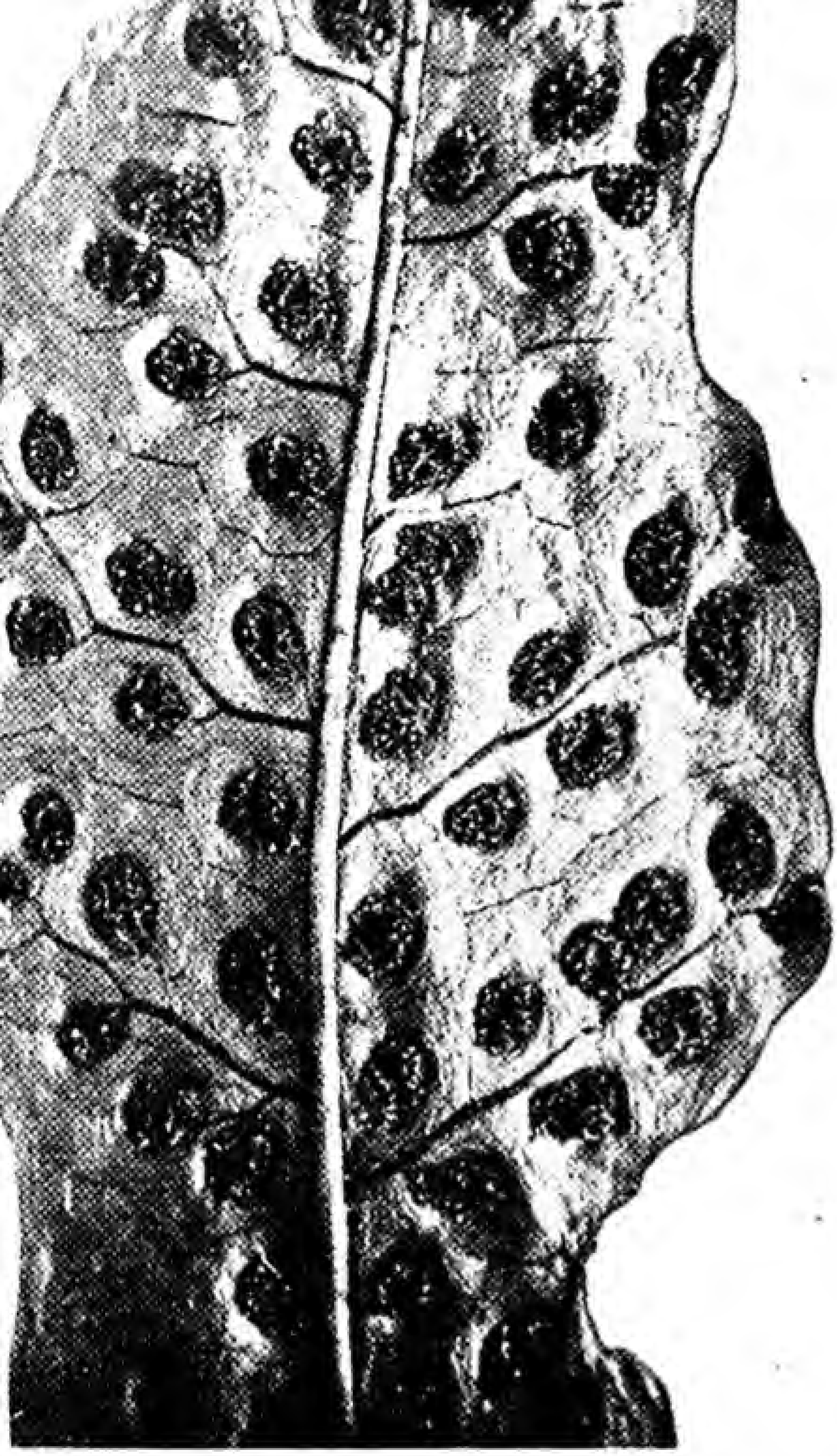
FRUITS OF MOSS

Moss fruit capsules, which are borne at the end of long, leafless stems. As a capsule matures, its inner cells divide and form numerous spores. When ripe, the capsule opens and the spores are distributed like a small cloud and are carried away on the air.

female plants grow in close proximity to one another in the tuft of *Funaria*, so that the whole crowded surface of the colony easily becomes enveloped by a continuous film of water during damp weather.

Into this film of water the motile sperms are discharged and make their way to the archegonia. Fertilization of the single egg cell of the latter is effected by a sperm making its way down the long neck of the flask and fusing with the female cell at its base. The egg cell then secretes a cell wall around itself, and is termed a zygote. The body ultimately developed by this fertilized egg cell, is the moss capsule or fruit, which is borne on the end of a long, leafless stem as an oval body, the sporophyte. In due course the capsule of the sporophyte becomes filled with spores, which when ripe make their exit through an aperture at the top of the capsule, and on falling to the ground germinate; each spore giving rise to a new moss plant.

In the third great division, the Pteridophyta, which includes the ferns, the horsetails and club-mosses, the same regular



UNDER SIDE OF FERN LEAF

The dark patches are masses of spore-bearing organs called sporangia. When ripe each sporangium opens and liberates the spores, which are carried away by the wind.

alternation of generations occur as in the Bryophyta. Instead, however, of the gametophyte being the prominent form in the life-cycle, it is always a small cellular structure, usually of short duration; while the sporophyte forms what is commonly called the plant, consisting of stems, leaves and roots, and often persisting for many years. Thus in the common Male Fern (*Aspidium filixmas*), the sexual generation consists of a small heart-shaped prothallus bearing antheridia and archegonia.

As the result of fertilization, the central part of the egg cell or archegonium becomes much enlarged to make room for the developing embryo, which ultimately grows into the familiar fern, firmly rooted in the soil, and with a somewhat cone-shaped, stout stem from which the fronds or leaves arise. Thus, the ordinary fern plant is a purely asexual, or spore-bearing plant, the sporophyte, producing sporangia on the undersurface of its leaves containing the spores from which, in due course, will develop the heart-shaped prothallus, the gametophyte bearing the sexual organs.

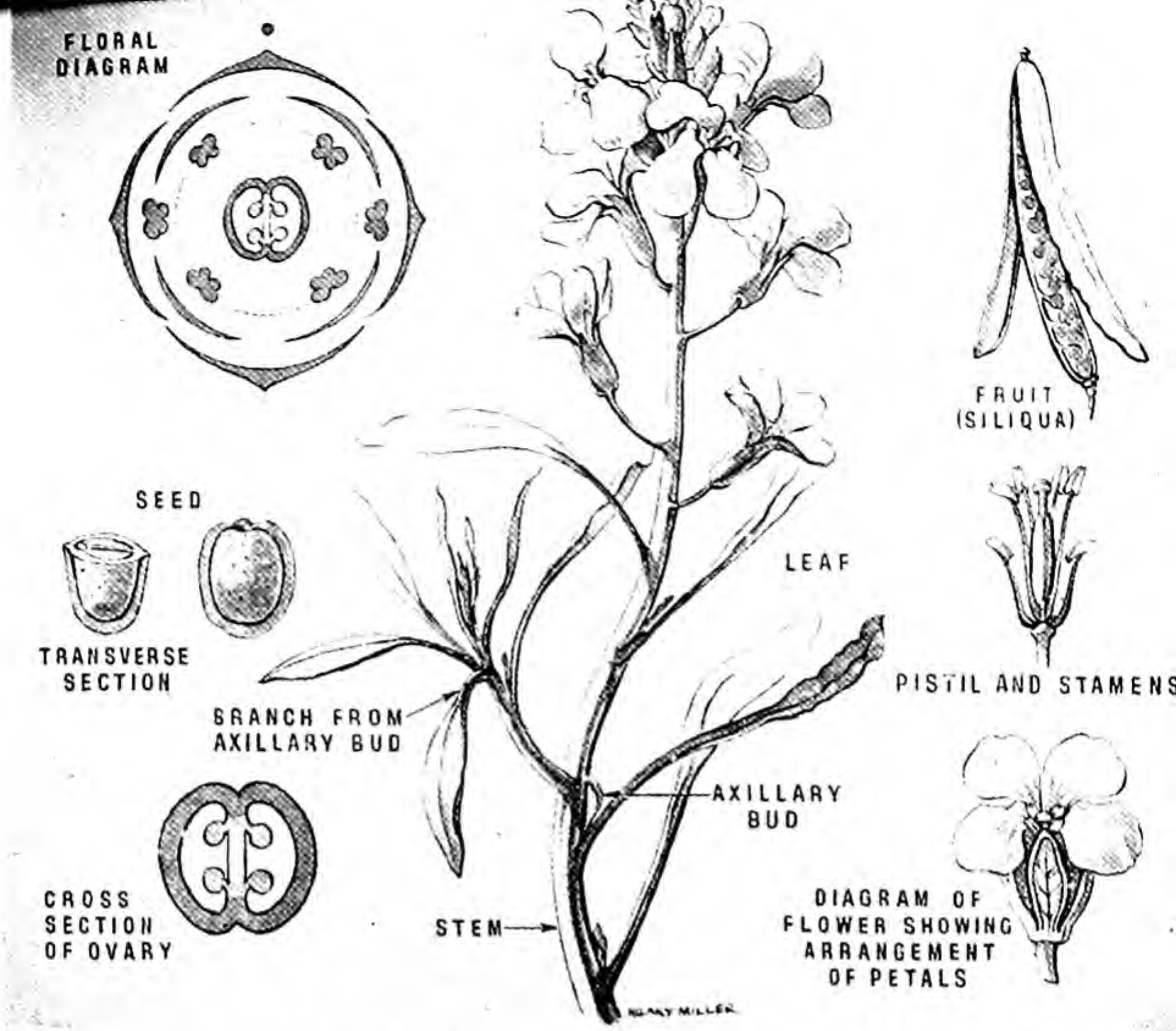
One particular feature that makes its first appearance among certain plants belonging to the Pteridophyta, is of special interest as a probable evolutionary link with the flowering plants or Phanerogams. It is the production of two kinds of spores, which differ chiefly in size, the very small being called microspores, and the much larger forms megaspores. Each type gives rise to its appropriate gametophyte, and is developed in its own type of sporangium. The microspore produces sperm cells or antherozoids, the megaspore the female cells or archegonia. Fertilization is effected by the entrance of a sperm into the archegonium and its fusion with the egg cell.

Selaginella

This feature may easily be observed in *Selaginella*, a native of South Africa, Madeira and the Azores, largely cultivated in greenhouses in Britain, and which has a creeping, much-branched stem. If a plant that is fruiting be examined, it will be found that some of the branches, instead of creeping along near the ground, grow straight upwards and form the terminal spikes or cones bearing the reproductive organs. Both kinds of sexual cells are borne on the same cone or spike; the male cells or microsporangia usually being the more numerous, occupying the axils of all the upper leaves, while the few larger female cells or megasporangia are formed at the base of the cone only. While the former contain very numerous minute spores (microspores), the large megasporangium contains only four spores (megaspores). In the higher plants, the Phanerogams, the pollen grains represent the microspores, and the embryo-sacs of the fertilized ovum the megaspores of the Pteridophyta.

Seed-producing Plants

We must now consider the process of reproduction as seen in the highest forms of plant-life, the Phanerogamia, or Spermophyta, which differ from all the other



FLOWER AND FRUIT OF WALLFLOWER

All the floral organs of the wallflower are arranged symmetrically around the pistil, which is nearly cylindrical in shape, tapering towards the top and terminating in the stigma, the organ which receives the pollen grains; through its tissues the pollen-tubes pass to fertilize the ovules. The wallflower has a dry, dehiscent fruit called a siliqua.

divisions of the plant world in that they produce seeds. Moreover, they also differ from most of the others in that the majority bear more or less conspicuous and beautiful flowers, highly organized and usually followed by the production of fruits. The flower, no matter what its size, shape or colour may be, is regarded as a shoot whose leaves are modified in connexion with the production of sexual organs, and in many instances further adapted to promote cross-pollination through the visits of insects, such as bees, butterflies, etc.

Arrangement of Flower

A complete symmetrical flower consists usually of either four or five whorls of alternate leaves, placed immediately one within the other. Each set of these modified leaves is known by a distinctive technical name and each performs a different function. As a familiar flower, and one generally to be found in most gardens, we may take the common wallflower; taking care, however, not to select a plant bearing so-called double or monstrous blooms. In the normal flower, the end of the stalk on which it grows is called the receptacle; the rest of the stalk, termed the pedicel, is quite bare.

The floral leaves growing out from the receptacle are not arranged spirally, but two or more grow at the same level, forming as it were a series of rings one within the other. Beginning at the outside of the flower and working inwards, we first find four small narrow leaves growing in two pairs placed at right angles to each other

Each of these four leaves is called a sepal and, collectively, they form the calyx. Inside the calyx we find four floral leaves forming again a single ring or whorl. These are the petals, the most conspicuous part of the flower, and form collectively the corolla.

The next whorl is quite different in appearance, composed of bodies not at all resembling leaves. Each consists of a longish stalk, bearing at the top a little boat-shaped yellowish coloured case. These are the stamens, or male organs, and in the flower we are describing there are six of them, four being longer than the other two. The stalk of the stamen is termed the filament, and the body on top of it is the anther which, when ripe, bursts to discharge the golden-yellow pollen grains. Finally, the middle of the flower is occupied by the female organ, the pistil, which in the wallflower is a nearly cylindrical body, tapering a little towards the top, and surmounted by a forked outgrowth, the stigma. The lower, thicker part, which occupies rather more than three-quarters of the length of the entire pistil, is the ovary in which the ovules or seeds develop, while the short tapering portion connecting it with the forked stigma, is the style.

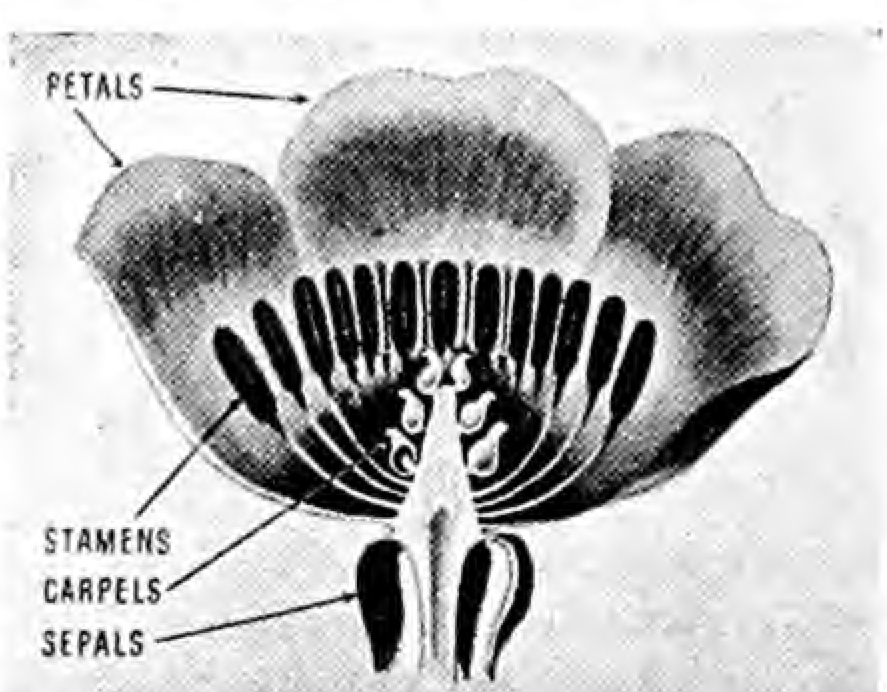
Ovary of Wallflower

The ovary in the wallflower is divided lengthways into two compartments by a partition wall or septum, which marks the boundary between the two carpels, which is the name given to the floral leaves of which the pistil is composed. Within the ovary are the young seeds, or ovules as they are termed prior to fertilization, and they grow on the walls of the ovary adjoining the septum. The ovules only develop into seeds after fertilization, which is brought about by the transference of the pollen grains to the receptive surface of the stigma. The surface cells of the stigma secrete a slightly sticky fluid containing sugar in solution, which the pollen grains absorb. As a result, each develops a pollen tube which penetrates between the stigmatic cells into the tissues of the style, ultimately reaching an ovule which is ready for fertilization. Finally, the generative nucleus of the pollen grain reaches the nucleus of the ovum, and the two nuclei then fuse together into one and fertilization is effected.

Complete Flower

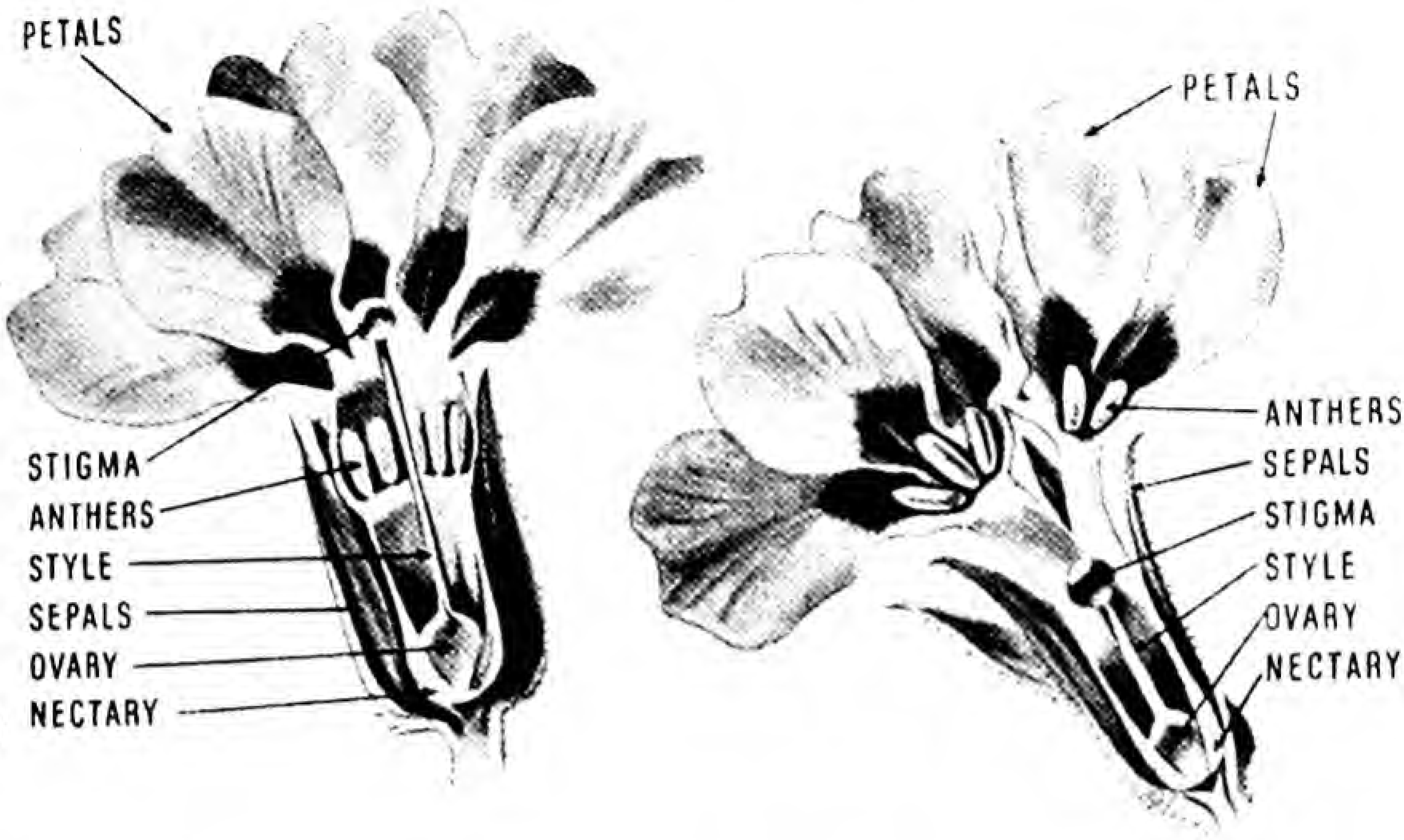
In the wallflower, all four types of floral leaves—sepals, petals, stamens and pistil—are present and, therefore, the flower is termed complete. In many plants, however, we shall find that the male organs (stamens) are borne alone on one flower (staminate flower) and the female organs (carpels) on another (carpellary flower), or the floral leaves may be reduced to sepals, as in the wood anemone and larkspur; or further modified, or replaced by what is termed a spathe enclosing the sexual organs, as in the cuckoo pint, where it surrounds the flowering axis bearing the sessile ovaries and anthers.

The variations in shape, colour, size and position of the components of the flower in Angiosperms are most remarkable, their modifications being largely the result of adaptations for obtaining the benefits to be derived from cross-pollination, particularly through the visits of insects. The simplest method of pollination is the transference of the pollen from the anther to the stigma of the same flower, termed self-pollination. When, however, the stigma of a flower receives pollen from the flower of another individual plant of the same kind, it is then said to be cross-pollinated.



FLOWER OF BUTTERCUP

Longitudinal section showing principal parts. The fruit is a collection of dry achenes on a receptacle.



TWO TYPES OF PRIMROSE

Thrum-eyed form on right ; pin-eyed on left. The two forms are borne on separate plants and assist cross-pollination, which is effected by bees. When a bee visits a thrum-eyed flower and pushes its long proboscis down to the bottom to obtain nectar, its head brushes against the ripe anthers and becomes dusted with pollen. The same part of the bee's head comes into contact with the stigma when it visits a pin-eyed flower.

Finally, pollen may be transferred from the anthers of one flower onto the stigma of another flower of the same individual plant; a half-way stage between cross-pollination and self-pollination.

Survival of the species depends upon the production of seed by the individual plant, and that can only occur through the fertilizing influence exerted by the pollen nucleus on the ovule. Hence the many devices that have been developed to assure successful transference of the pollen grains from the anthers to the stigma.

Although many flowers are self-pollinated, either spontaneously or by the agency of insects, and this may seem the most obvious and certain method, careful experiment and observation have long ago demonstrated conclusively that superior results are obtained through cross-pollination. This results in the production of larger numbers of seeds, and of seeds having better germinating qualities, and more readily developing into stronger, more virile plants. While cross-pollination must rank as of primary importance, circumstances do arise on occasion, which prevent its successful accomplishment.

To guard against such a contingency, many plants in addition to possessing conspicuous flowers which are cross-pollinated through the visits of insects, provide for self-pollination either by final growth or movement of the anthers or of the stigma. Sometimes they develop small, inconspicuous, often bud-like flowers of quite different form, that may never open, cleistogamic flowers as they are called, as in the woodsorrel and violet.

The arrangement for hindering self-pollination may roughly be grouped under four headings: (1) the stamens and carpels do not occur in the same flower; (2) the stamens and carpels in one individual flower ripen at different times, with the result that though the flower possesses both organs the anthers and the stigmas are not ready for pollination at the same time;

MALE YEW FLOWERS
They grow on the underside of the twigs in the axils of last year's leaves.

FEMALE YEW FLOWERS
Inconspicuous flowers. Each contains one ovule, surrounded by a single integument.

(3) the pollen has no fertilizing effect on the ovules of the same flower, consequently when the stigma receives pollen from the same flower no seeds result; (4) the relative arrangement of the parts of the flower may be such as to prevent the pollen reaching the stigma of the same flower.

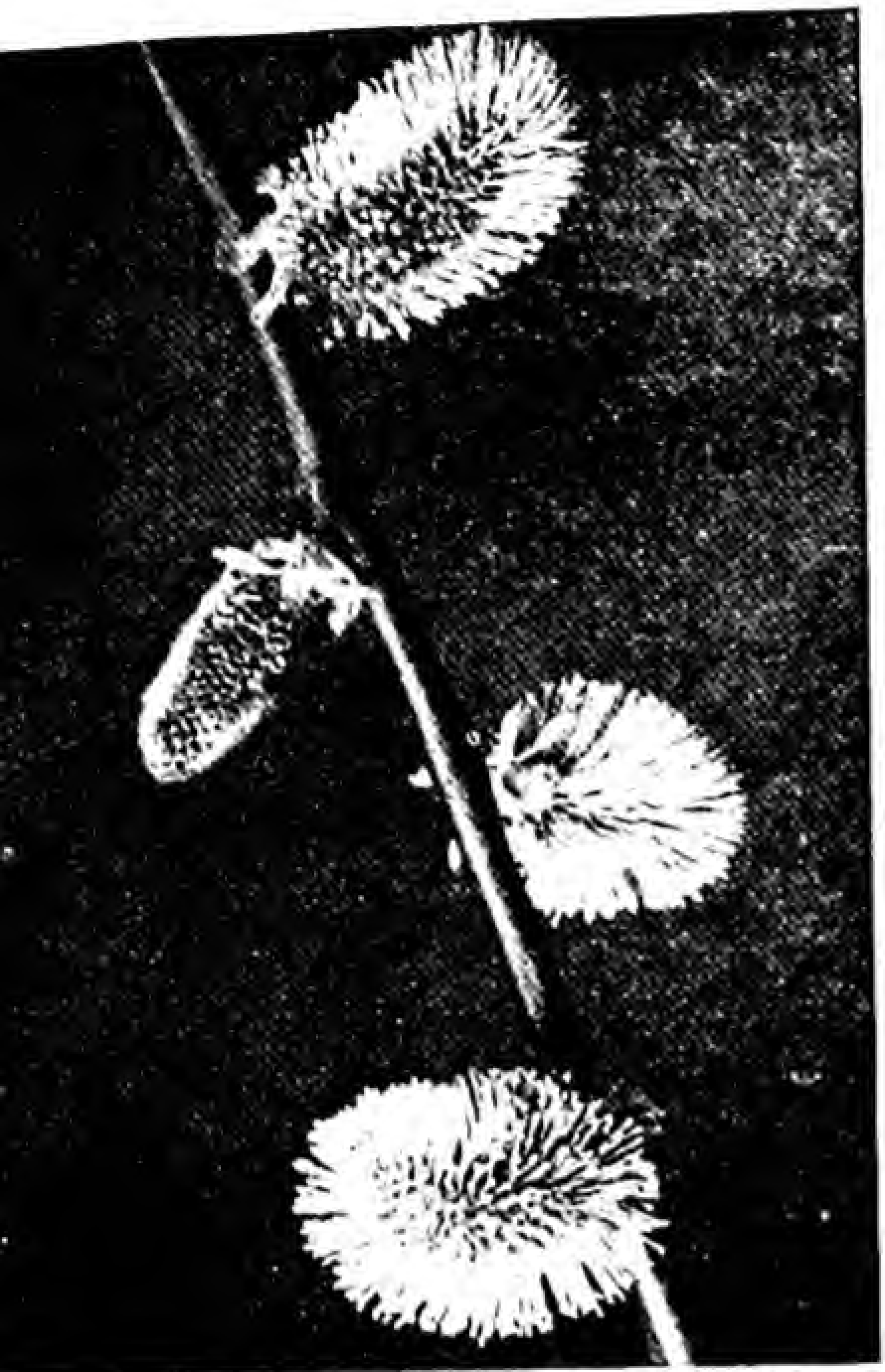
Wind or Insect Pollination

The benefit of cross-pollination may be brought about either by the aid of the wind, or through visits from winged insects; while in sub-tropical and tropical countries there are some flowers which are pollinated by small birds, the tiny jewel-like humming birds, which hover in front of tubular flowers, being familiar examples.

As British examples of wind-pollinated flowers we may cite the hazel, birch, alder, hornbeam, poplar, hop, dog's mercury and the grasses. It will be found that all have small, inconspicuous flowers destitute of honey-nectaries; their anthers are usually attached to long pendulous filaments, so that the abundant, dry, powder-like pollen is easily shaken out by the wind. Their stigmas are well-developed, often feathery or thread-like and present a relatively large exposed surface to receive any wind-borne pollen.

The yew and all the different species of pine trees are dependent upon the wind for the transference of their pollen from the male to the female cones. In early spring the long, bright green catkins of the hazel are very noticeable and at the least touch when ripe, shed their pollen. The female flowers, however, are not so conspicuous, each resembling a fat bud from the tip of which a tuft of red, short threads, the stigmas, protrude.

In marked contrast, insect-pollinated flowers are usually conspicuous, brightly coloured or white, and often scented. Moreover, they usually possess special glands or nectaries yielding the sweet,



MALE SALLOW CATKINS

Male and female flowers grow on different trees. Such plants are called dioecious.

FEMALE SALLOW FLOWERS

Pollen is carried to the female by the wind. Sallows are noted for their early flowering

sugary secretion for which insects visit them. In some instances, however, as in the poppy for example, in place of the sweet secretion an abundance of pollen is produced as an attractive food supply for visiting bees. The pollen grains, instead of being dry and powdery, are usually slightly sticky so that they readily adhere to the body and limbs of visiting insects. The stigma is not feathery or threadlike, but as a rule, relatively small, and there is a certain definite correspondence between the positions of the anthers and stigmas. Of course, there are exceptions to these general statements, and so we shall find that some insect-pollinated flowers are inconspicuous and apparently scentless.

Let us just briefly examine some of the advantages obtained by insect cross-pollination compared with wind cross-pollination. A flower visited by insects has the advantage that it is pollinated by creatures which move in definite directions, that is, from flower to flower. With wind-pollinated flowers, on the other hand, the pollen is blown about in any direction, so that for every pollen grain that reaches the stigma of another individual plant of the same kind, literally millions of other pollen grains fall to the ground and are wasted. Consequently, the insect-pollinated flower can afford to produce very much less pollen.

Moreover, the various colours and scents of flowers serve a double purpose, not only attracting insects, but assisting them to identify the particular flower they wish to visit. On any sunny day you may witness how the bees will confine their visits to one particular kind of plant the whole morning, flying direct to those plants without any hesitation; so here again there is no wastage of pollen.

Flowers of different shapes and tints do not receive equal attention from all kinds of insects; they have become adapted to

FROM BLOSSOM TO FRUIT

General view of the handsome bell-shaped flower. It is pollinated by bees. Datura is a shrub the leaves and seeds of which produce a poison similar to belladonna.

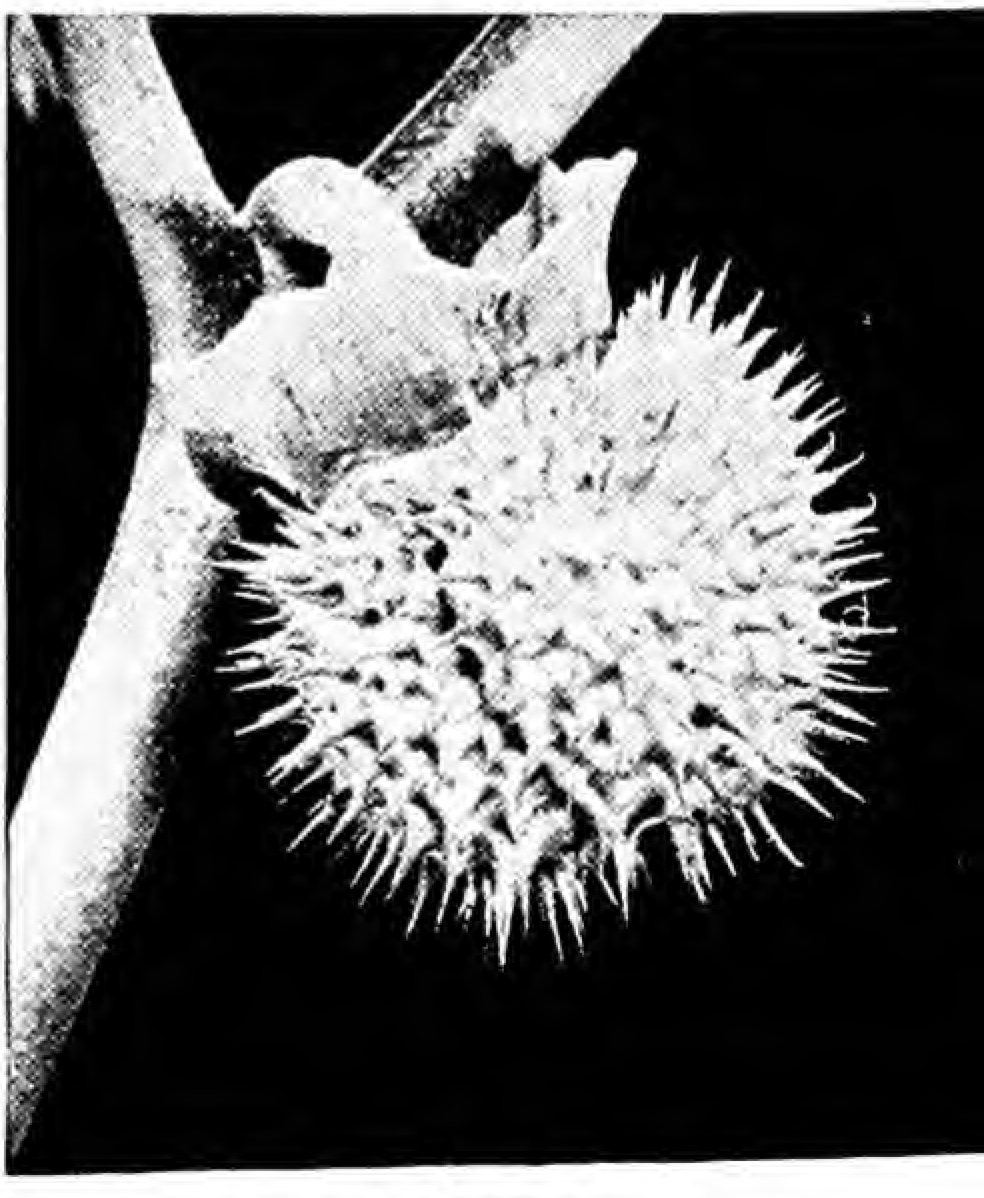
receive the visits of those particular insects which are best fitted in one way or another for the successful transfer of the pollen from the anthers to the stigma.

Thus the flowers of the pea, vetch, clover and violet have their honey glands well concealed so that only insects with relatively long tongues can reach the nectaries. They depend for their pollination entirely upon the visits of bees and, therefore, are often called bee-flowers. The foxglove, monkshood and snapdragon are especially adapted for cross-pollination through the visits of humble-bees, who alone can accomplish it.

Trumpet and tubular-shaped flowers, such as convolvulus, campions and honeysuckle, depend chiefly upon the visits of butterflies and moths, whose exceedingly long tongues can reach the deeply seated

BUMBLE-BEE

Close-up of bumble-bee on stamens of a Datura. The bee is well powdered with pollen.



DATURA FRUIT

Close-up of fruit of Datura. It has a toughened pericarp covered with fine hairs.

nectaries which are not fully accessible even to the longest tongued humble-bee. Flowers like those of many Umbelliferae, the parsley tribe, and the buttercups, in which the nectaries are freely exposed or scarcely concealed, are visited by short-tongued insects such as beetles, flies and wasps. Moreover, in those flowers which depend upon the visit of one particular type of insect, the anthers and stigma are so arranged that only that insect can successfully effect cross-pollination. Unwelcome insects are either deterred, or actually prevented in various ways from reaching the honey provided as recompense for the rightful visitor.

The result of fertilization is that the ovule grows and becomes a seed; the vital change in the ovule being that a part of it becomes a minute plant, the embryo, which now develops within the embryo sac, which becomes stored with a nutrient called the endosperm that surrounds the embryo. This endosperm may be present still in the seed, or may be absorbed gradually by the growing embryo, so that in the ripe seed no trace of it remains. In the first, we have what is called an endospermic seed, such as is seen in the grasses and violet, while where no trace remains the seed is said to be non-endospermic, as for example, in the bean and wallflower.

The consequences of fertilization are by no means confined alone to the ovules, for the carpels, and frequently others parts of the flower, are stimulated into further vigorous growth, while the petals and sepals wither and fall off more rapidly than would have happened had fertilization not taken place. One part of the flower, however, invariably persists, and that is the ovary, which remains to form a protective case, the pericarp, around the ripening seeds. The corolla and stamens wither, and consequently take no part in the formation of the fruit, whereas the calyx frequently persists.

As an example of a familiar plant possessing one of the simplest fruits, let us take the pea. Its ovary, composed of one carpel, enlarges after fertilization and becomes the familiar pea-pod, constituting the fruit, inside which are the seeds. In the wallflower,

FRUIT IN SECTION
Longitudinal section of Datura fruit showing arrangement of the seeds within.

OVARIES OF DATURA
Transverse section through base of Datura blossom, exposing ripening seeds.

which we took as an example of a complete flower, the ovary differs, being composed of two carpels, but as in the pea, it is the single ovary alone which, by its growth, gives rise to a single fruit. Both these flowers, therefore, have what are termed simple fruits. Where a flower has a number of ovaries, the buttercup or the lesser celandine, for example, each ovary enlarges and eventually encloses one seed.

Such a flower thus possesses a number of seed-containing vessels, each similar to the pea-pod in so far as it consists of a single, ripened carpel, but collectively forming what is termed a compound fruit. A dandelion head, on the other hand, cannot be classed as a compound fruit, for it is formed as a result of the fertilization of a number of flowers, the sexual individuals composing the disk of the flower-head, and therefore constitutes a collection of fruits, an infructescence as it is termed. In the pea, wallflower and buttercup we have examples of what are termed dry fruits, while the apple, cherry, plum, currant and strawberry possess what are termed fleshy or succulent fruits.

Fertilization of Gymnosperms

We must now briefly consider the process of fertilization in the Gymnosperms, taking for our type the familiar Scotch pine. We have seen that in the flower of an Angiosperm the ovule is enclosed in an ovary or seed-case, and that in consequence fertilization has to be effected by the passage of the pollen tube down through the tissues of the stigma. In the Gymnosperms, however, the process is relatively much simpler, the pollen grain or male cell being brought directly into contact with the ovule or female cell. In the *Coniferae*, the family to which the Scotch pine belongs, all are wind pollinated and produce large quantities of dry pollen.

The Scotch pine has two kinds of flowers; one possessing stamens, the other bearing carpels. Both are to be found growing on branches of the same tree and take the form of cones, the male cones being smaller and borne near the apices of the flowering shoots. The stamen-bearing flowers consist of yellowish tinted cones clustered together. Each cone is a single flower borne on a short stalk. The simple axis of the cone has a basal portion which bears what are called bract scales. Above these are inserted lateral scales, each of which has two pollen sacs attached to its lower face. These latter scales are, therefore, the stamens of the flower, which thus consists actually of a simple axis—the receptacle—with spirally arranged stamens.

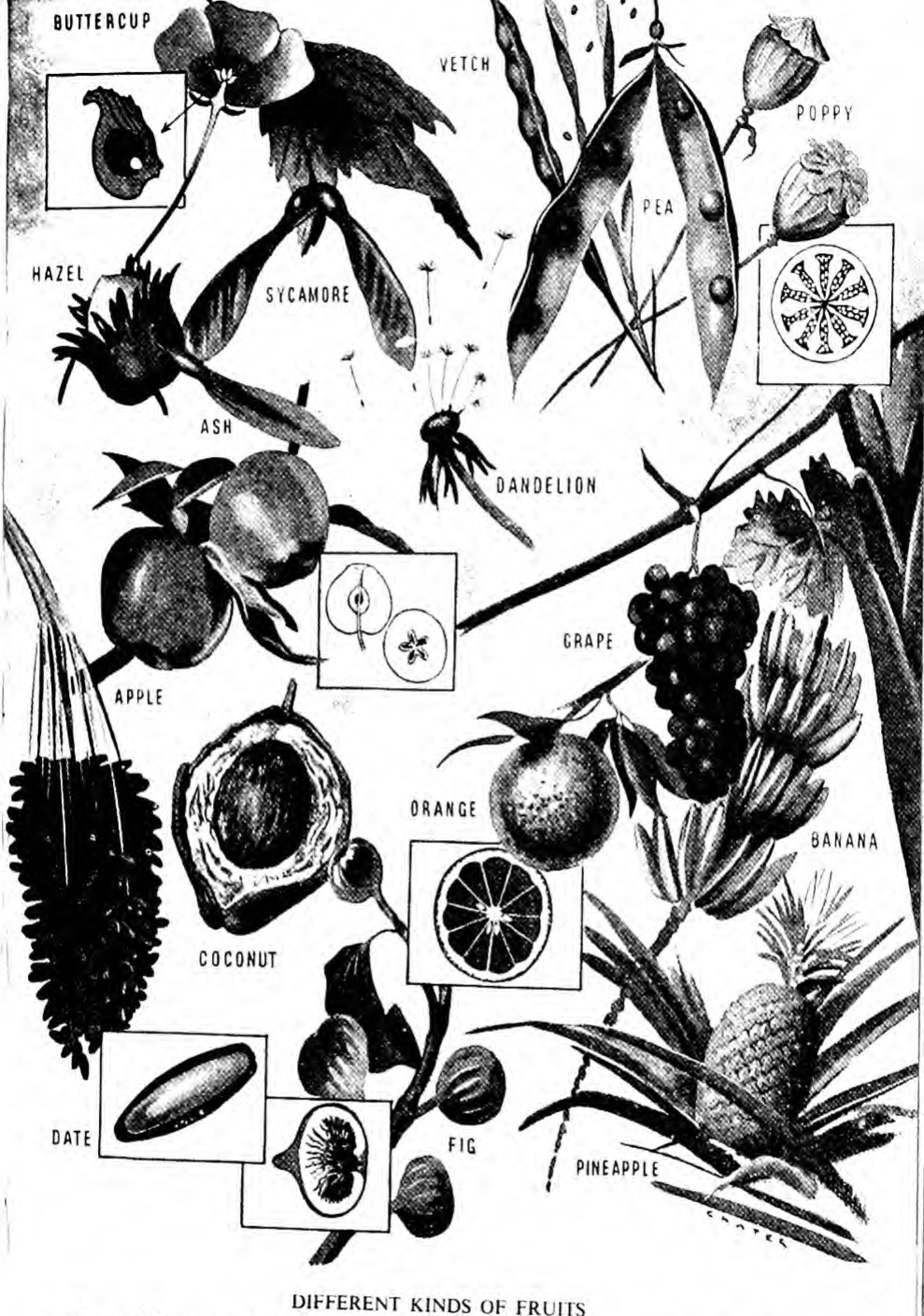
Carpel-Bearing Flowers

The carpel-bearing flowers are also cone-shaped, but more complex in structure, and at first appear as erect reddish buds. Each cone at its base bears a few simple bracts, above which are scale-like members of somewhat complicated form, each consisting of a small scale from the upper surface of which a larger scale protrudes, while again attached to the upper surface of each larger scale are two ovules.

These peculiar double scales are carpels, for they bear ovules, and they are arranged spirally on a simple axis or receptacle. When ready for pollination in May, the carpellary cone stands erect and its axis elongates, thus causing the carpels to separate to a slight extent. The wind-borne pollen grains are blown against the female cones, and in this way some of them reach the crevices between the carpels. They then roll down the prominent rib of the placental scales, and thus meet the integuments (or outer coats) of the ovules. The integuments then curl up slightly and carry the pollen towards the micropyle (tiny opening at the end of ovule).

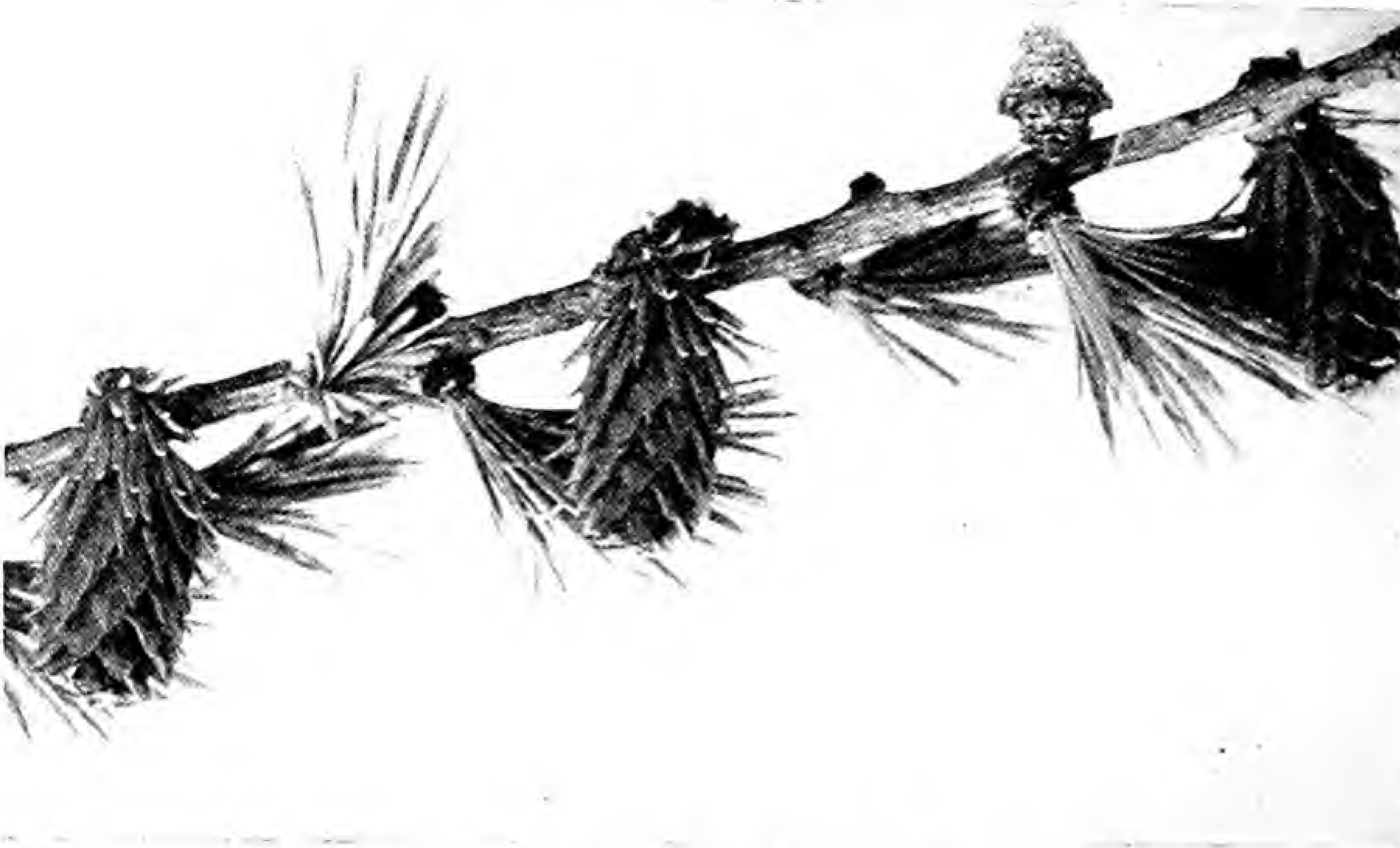
Pollination of Pine

Thus, in the pine, the pollen grain itself reaches the micropyle of the ovule, whereas in Angiosperms it is only conveyed as far as the stigma, down which its developing pollen tube has to penetrate before reaching the ovule. After pollination has thus taken place, the carpels again close together, and the placental scales become hard, green and woody. Each cone gradually bends over until it finally points downwards, and its closely set scales become brown in colour. As a result of fertilization, the ovule develops into a hard seed containing an



DIFFERENT KINDS OF FRUITS

Fruits of flowering plants are divided broadly into two main groups, those in which the pericarp is dry or hard, like a pea pod or a hazel nut, and those which have a soft or succulent pericarp, like a plum or an orange. Dry fruits can be dehiscent or indehiscent. The grape is a berry, one of the simplest types of succulent fruits



FLOWERS OF LARCH

Plants which like the larch bear male and female flowers on the same plant are said to be monoecious. The two types of flowers often form at different dates.

embryo which possesses a whorl of cotyledons (seed-leaves). Attached to the seed is a separate wing which is not really a part of the seed, because it is formed by a layer of the scale.

The escape of the seed from the cone does not take place until more than a year after pollination. A few may escape in the autumn of the year following fertilization, but the majority remain in the cone for about two years, when the woody carpels gape wide apart as they dry. The wings are an adaptation of structure, serving as parachutes by the aid of which the seeds are scattered by the wind, causing them to spin and so prolong their journey before reaching the soil. Finally, the cones fall from the trees and are rolled along the ground by the wind, scattering afield any seeds which they may still harbour.

Parts and Their Functions

We may briefly summarize the functions of the parts of flowers, fruits and seeds in the Phanerogamia as follows:—

(1) The calyx usually protects the young developing flower; it may be green, or coloured; may possess honey nectaries; may aid in the dispersal of the seeds by the wind, as in the dandelion.

(2) The corolla serves by its shape, colour and nectaries to attract those insects which will effect cross-pollination.

(3) The androecium, or collection of stamens in a simple flower, produces the pollen indispensable for fertilization and the production of seed.

(4) The gynaecium, the collection of carpels within a single flower, produces the ovules. Of its various parts, the ovary protects the ovule; the stigma receives the pollen grains; the style raises the stigma to the proper height and position to bring about cross- or self-pollination.

(5) The pericarp protects the seeds and often helps in their dispersal. It may be bright in colour and fleshy to attract animals.

(6) The testa or seed-coat serves to protect the embryo and food-substance of the seed. Consequently, it is thin and delicate when the seeds are adequately protected by the pericarp, but well developed where no stout pericarp exists.

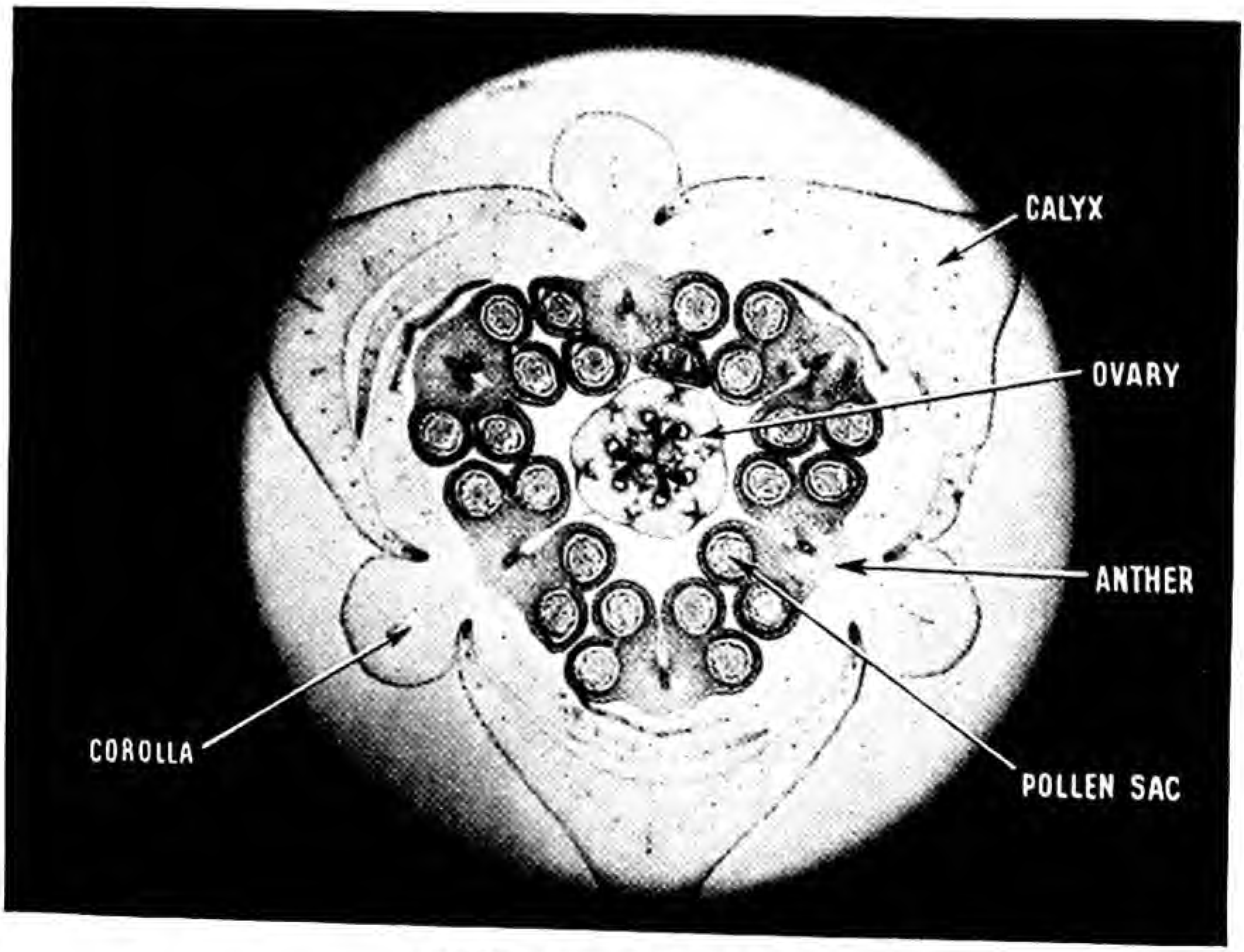
(7) The various outgrowths, wings, hairs and hooks, seen on seeds and fruits are

structural adaptations to facilitate the dispersal of seeds. Sometimes hooks or spines may also help to protect the fruits against animals which otherwise might eat them and destroy the seed.

The average individual is apt to look upon a handful of dry seeds as so many bits of inert matter; of no particular interest save, perhaps, to be planted, more or less hopefully that some result will ultimately show above ground. Well, seeds are very much living things; they are the children of the plants, stored at this stage of their existence with latent energy and dormant life, only awaiting suitable conditions for their awakening. Let us, therefore, examine a plant-seed a little more closely, perhaps, than we have ever done before. A broad bean seed is convenient for the purpose because it is easily obtained and, being a large seed, more convenient for naked-eyed scrutiny.

We shall see that it has a tough outer seed coat, which is called the testa, and that the most noticeable external feature is the long dark patch, the scar as it is termed, now representing all that is left of the tissues by which the seed was held in place, and received its nourishment, during development in the bean-pod. If we look carefully, we may be able to detect a very small opening or pore, the micropyle as it is termed, at one end of the scar. The whole space within the seed coat is occupied by the dormant embryo, consisting of a small rod-like body or main axis, with two large fleshy leaves, called the cotyledons, which are attached, one on each side, at a point near the centre of the embryonic stem, called the hypocotyl. The tissues of these cotyledons are richly stored with food supplies (starch, etc.) necessary for carrying on the first stages of growth during germination.

On carefully drawing the large cotyledons apart, we can see the little rod-like embryo



FLORAL ORGANS OF LILY

Transverse section through bud of orange lily showing arrangement of the floral organs. The ovary is three-chambered and the fruit is a capsule opening by three valves at the tip.

body composed of three parts: the primary main stem terminating at its upper end in a minute bud known as the plumule, and at its lower end in the primary, pointed root, called the radicle; and the central part of the stem, the hypocotyl, connecting root and stem, to which the cotyledons are attached.

We may also be able to see that the tip of the young root lies close within the minute pore or micropyle of the seed coat. Plants having two cotyledons are called dicotyledons; those possessing one are known as monocotyledons, while the embryos of Gymnosperms, flowering plants with naked seeds, have many, and are described as polycotyledonous.

Conditions for Germination

Only when climatic conditions remain suitable; that is to say, when the temperature is sufficiently high and constant, and humid weather provides sufficient but not excessive moisture in the soil, does the process of germination, the further development of the tiny embryo into the seedling plant, begin. The layer of cells forming the outer wall of the seed coat are mucilaginous, and taking up water readily and in considerable quantity, swell into a slimy, sticky coating, thereby helping the seed to retain more firmly its position in the soil. Part of the fluid thus absorbed is passed on to the embryo within, reawakening it from its long winter rest to renewed energy. Its mid-stem, or hypocotyl, and radicle rapidly begin to elongate so that the tip of the latter is soon forced out through the pore in the seed coat.

From the very beginning of germination, the two developing ends of the central axis of the embryo start upon a settled course from which nothing will divert them—the ascent into daylight and air on the part of the stem, the descent into the soil, away from the light, by the radicle. In no matter what position the germinating seed may lie, on or in the soil, as soon as the radicle has pushed itself free from the seed coat it will curve so that its tip is directed straight downwards and at once penetrates the soil. At the same time, the hypocotyl is making equally rapid growth in the opposite direction and making any necessary curvature to bring the apex of the stem to point skywards.

The cotyledons for a time remain more or less imprisoned in the seed coat, and are usually lifted by the upward growth of the stem above ground. There they expand and, becoming green, pass from being storage receptacles to function as assimilating leaves, capable of forming new organic substance on their own account. In some plants, however, as in the broad bean seed we have been examining, the cotyledons are not carried well above ground, but simply continue to function as receptacles until exhausted of their food reserves. Once well above ground, the apex of the stem begins further development and puts forth leaves capable of carrying on assimilation and respiration; while the young root, having penetrated the earth, immediately begins to develop root hairs which serve to draw in mineral salt solution from the soil, and root branches which ramify among the soil particles making a firm anchorage during the subsequent growth of the plant. Germination has thus successfully been accomplished, and the embryo has developed into the youthful plant.

Classification of Fruits

The word fruit usually calls up a mental picture of an apple, pear, plum or cherry, but as we have learned, the botanist applies this word as a general term to that part of the flower which persists after fertilization until the seeds are ripe and, consequently, to an object varying greatly in shape and size, which is often quite different in appearance from the layman's concept of a fruit. To meet this difficulty, the botanist has classified the various kinds of fruits according to certain well-marked characteristics, first dividing them into two distinctive groups: (1) dry fruits, in which the pericarp is thin, dry, hard or brittle; and (2) fleshy or succulent fruits, in which the pericarp is more or less soft and often brightly coloured. Familiar examples of the former type are the long pods called legumes of the pea, beans and clovers; the somewhat pod-shaped fruit called a siliqua, typical of many cruciferous plants, as seen in the

wallflower and shepherd's-purse; the barrel-shaped seed pod called the capsule, of the poppy; and the hard, stone-like pericarp called a nut, of the hazel and walnut.

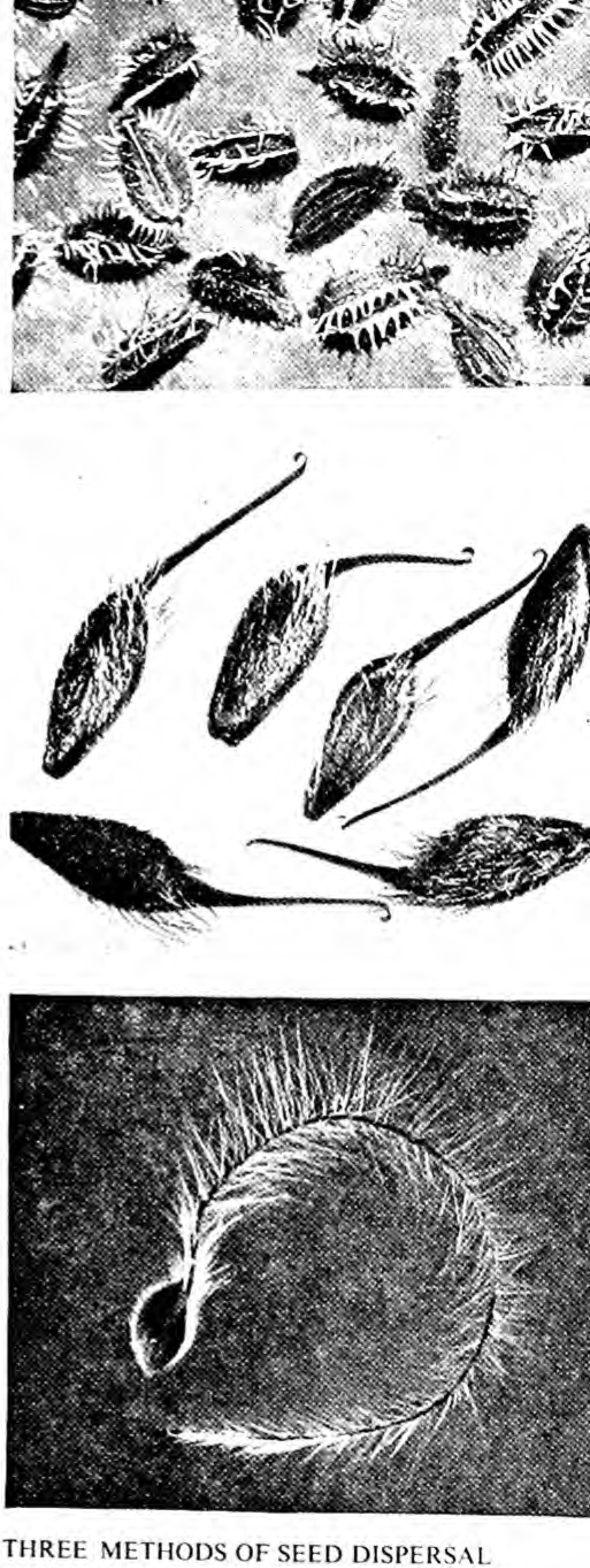
Succulent Fruits

Turning to the second group composed of succulent fruits, the soft, beautifully coloured fruit of the plum, apricot and cherry is termed a drupe. The characteristic of this type is that the innermost layer of the pericarp enclosing the single seed is stonelike, the middle layer more or less soft and juicy, and the outer layer a very delicate and tinted thin skin. In the apple and pear the fruit is termed a pome. The seeds are contained in five horny ripened carpels, while the receptacle grows vigorously and remains fleshy. In fact, the pome is peculiar and is regarded as a very special type of fruit.

Another special type of fruit is found in the blackberry and types related to it, such as the raspberry and loganberry. In these plants a number of drupes grow together on a common receptacle and form what is called a compound fruit. In the grape, gooseberry and currant, the pericarp is soft throughout, and the fruit is termed a berry.

All these various forms of fruits represent different devices for obtaining the best possible means of dispersal of the seed. Unless this can be successfully accomplished so that the seeds may reach favourable situations at an appreciable distance from the parent plant, they are likely never to reach maturity, owing to overcrowding with its resultant lack of light and air and space in which to develop, and the exhaustion of the necessary chemical constituents in the soil. Wide dispersal is imperative if the species is to survive.

The production of large quantities of seed is not all-sufficient unless accompanied by effective means of distribution, and where it exists it generally points to a very high death rate at some stage in the life-history of the seedling plant. Therefore, we find that the means for effective dispersal is not confined alone to the form and character of the fruit. The seeds themselves are often still further provided individually



THREE METHODS OF SEED DISPERSAL
Wild carrot (top picture), capsule splits open and scatters seed; common avens (centre), hooked seeds attach themselves to passing animals; wild clematis (bottom), seed has a feathery attachment for wind dispersal.

DANDELION BUD AND FRUIT

The dandelion has a type of inflorescence known as a capitulum, consisting of a collection of small florets within a cup-like arrangement of bracts. The seed develops a long thin stem topped by a tuft of white silky hairs, like a dainty parachute, on which it travels through the air.

with adaptations of outward structure or shape to this end. We have already seen in the Scotch pine an example of such combined structure for effective dispersal, the light seeds possessing a wing-like structure which acts as a parachute, while the fruit on account of its cone-like shape is easily rolled about when it falls to the ground, so that the remaining seeds within its scales will be further scattered.

Dispersal of Seeds

In the thistles, dandelion, rose-bay willow-herb and cotton grass, with their delicate feather-like parachutes, and in the familiar keys of the lime and the sycamore, we have beautiful examples of the development of effective means of dispersal by the wind. In some species of *Geranium*, of which the Herb Robert is a familiar example, the fruits are explosive capsules, and when ripe the carpels open and the seeds are violently slung out. In the wild violet, the capsule opens into three boat-shaped valves, each containing a double row of highly polished seeds.

The sides of the valves contract as they dry, and in doing so the seeds are shot out to an appreciable distance. As the seeds are small, light, smooth and easily rolled along, they are carried still farther away from the parent plant by gusts of wind. Eventually they fall into cracks and crannies in the soil which become filled up with earth washed in by the rain, so that after their winter dormant rest the seeds are in a favourable position to germinate on the return of warmth and sunshine the following spring.

Many fruits possess hooks and rough or sticky surfaces by which they are able to adhere to the coats of passing animals, or the clothing of people that in passing may brush against them, and thus are provided with the means for a wider distribution. The fruits of the common agrimony, the wood avens or herb bennet, and the cleavers and the burrs of the burdock, are all familiar examples to be met with during an autumn country ramble.

Lastly, we have the succulent fruits whose conspicuous and fleshy coats are intended to attract and invite animals to eat them, where the seeds are protected either by an indigestible stone or a hard skin (testa), and so pass through the digestive tract of the animal uninjured.

Many flowering plants are able to increase in number without the intervention of seed production, and to multiply by a vegetative process in which portions of the plant become separated from the parent-plant by the decay of parts connecting them to the latter. These disconnected young outgrowths produce roots of their own and so establish themselves as distinct individuals. For example, the long internodes of the strawberry-runners may decay,

and the tufted shoots at each node form roots, and become separate plants. We can see the same thing take place in the tubers of a potato, each becoming detached from the parent stem and in due course producing a new plant.

Again, the horizontal lateral roots of the blackberry, rose, hazel and poplar give off erect adventitious shoots, the so-called suckers, and these under favourable conditions will form roots and become separate individuals. The "cuttings" taken by gardeners also illustrate this vegetative method of multiplication in flowering plants.

Test Yourself

1. Which is the simplest way in which plants multiply?
2. How does reproduction in spirogyra differ from it?
3. What is the difference that distinguishes asexual from true sexual reproduction?
4. What is meant by an alternation of generations?
5. In what manner, apart from their general appearance, do mosses and ferns differ from flowering plants?
6. Why do some flower-bearing plants possess uncoloured, inconspicuous flowers, while others have conspicuous and brightly coloured flowers?
7. What is the chief reason for the many different shapes of fruits?

Answers will be found at the end of the book.

JOHANN GREGOR MENDEL (1822-1884)

Austrian abbot who experimented in artificial breeding of plants and animals. He discovered two important laws governing heredity transmission, now known as Mendel's Laws.

CHAPTER XII

THE STUDY OF HEREDITY

The classification of living things (Chapters II and III) is, of course, made possible only by the fact that the individuals of one generation constantly produce a succeeding generation of individuals identical with their parents in respect of a large number and wide variety of characters—details of structure, function, behaviour. Like begets like. The generic and specific characters are faithfully transmitted from one generation to the next.

Within the species there are the varieties, and the varietal characters, far fewer in number than the specific, are also true-breeding; in respect of them offspring closely or exactly resemble their parents. In the case of the domesticated animals and cultivated plants within the varieties there are strains, and again these, their distinguishing characters fewer in number than the varietal, are reproduced more or less exactly generation after generation.

The offspring of elephants are little elephants and none other. The Irish terrier and the pekingese are both dogs but belong to different breeds or varieties. The stamp of the sire or of the dam is imprinted on its particular offspring. The fertilized egg of a fowl cannot by any means be persuaded to produce a duckling. There are thus characters which the individual displays and which it comes to possess in virtue of its organic relationship to its parents.

But though two individuals belong to the same genus, species and variety, and though they are the progeny of the same parents, nevertheless they are not exactly alike. Each is the only one of its identical kind. Undoubtedly much of this variation must be ascribed to differences in experience. Human beings can and do differ markedly among themselves in respect of language, creed, preference. Differences in occupation can yield differences in posture, gait, habits; the calloused hands of the labourer are to be distinguished from those of the clerk. Differences in respect of illnesses, malnutrition, faulty education, can produce marked differences in stature and intellectual quality.

There is a social inheritance which the individual receives from previous generations and which he acquires in his own lifetime. There are modifications, characters which owe little or nothing to the organic relationship between the generations but which are the results of the reactions, the responses, of the living individual to the impress of forces in his external world. Nurture, as we call the sum of these external influences, undoubtedly largely moulds the characterization of the individual.

But nurture does not affect every potential character of the individual equally. If he belongs to a tall variety or stock, that is to say, if he is endowed in virtue of his organic relationship with an ancestry with the capacity to become tall, he may not realize such a potentiality if he is starved or suffers constantly from illness in infancy and childhood; but if he is potentially a blue-eyed individual, then whatever his experience he will still be blue-eyed. Fingerprint pattern, bloodgroup and a score of other characters are the imprints of nature and not of nurture at all. They are entirely predetermined by the fact that this particular individual is the offspring of those two particular parents.

There are thus two kinds of characters: (1) Modifications, which are the end results of the interplay between the individual and the forces of his external world, the responses of the individual to the environment (see Chapter VI); and (2) inborn, innate, hereditary or genetic characters, which are the direct expression of those forces (and of the material bases of these) with which the individual is endowed in his beginning as the direct consequence of the fact that he is the progeny of his parents.

It remains to consider the nature of these

genetic characters, their origin and the manner in which they are transmitted by parents to offspring from one generation to another.

The Gene

The beginning of the individual is two germ-cells, egg and spermatozoon, which unite to form one, the fertilized egg. (In some cases, the spermatozoon is not necessary, but these are exceptional.) If the material bases for the building of every part of the organism—for expressing every potential character—are to be found in these germ-cells, these two that unite, the male cell and the female, must be essentially equivalent to one another in their hereditary influence. Experiment has shown conclusively that they are. In each is to be found practically all the controlling material, the genetic material, which predetermines much of what the individual shall be.

It is present in the form of a number of rod-like bodies, the chromosomes, in the cell nucleus. In man there are twenty-four of these chromosomes in the nucleus of the egg and of the sperm. Each chromosome, different in size from all the others, consists of an extremely slender long filament coiled into a tight helical spiral, so tightly packed as to appear solid. But greater magnification shows that the chromosome is not a uniform mass, but is composed of hundreds of thousands of separable genetic elements, which we call genes, each of which, notwithstanding its extreme tininess, not only has a fixed place in the length of the chromosome but also has an individual make-up and purpose markedly different from those of any other gene. It can be shown that each gene has its own specialized role to play in determining the nature of the developmental processes which result in the appearance of a particular individual.

The genetic material consists of nucleoprotein, a compound of protein and nucleic acid. Proteins are among the most complicated substances known and are remarkable for their versatility. The number of types of protein, each with its distinctive chemical properties, is virtually unlimited, and some of them have enzymatic qualities, an enzyme being a substance which is able to bring about a specific chemical reaction between certain other substances without itself getting used up in the process. Nucleic acid belongs to that group of substances which are the most essential agents in all those transfers of energy in living systems in which any kind of physical work is performed.

The fertilized egg, the new individual and the new generation in its beginning, has in the sexually reproducing forms two sets of twenty-four chromosomes, one set having been received from each parent. The human fertilized egg, therefore, has forty-eight chromosomes, and these are arranged in pairs, the members of a given pair carrying the same genes arranged in the same order. This fertilized egg proceeds to divide into two. During this process of cell-division (called mitosis), all the genes undergo a doubling; each gene, that is, of all the hundreds in every chromosome, produces a new gene in its own image and built out of the materials in the medium around itself. As the result of this gene doubling a new string of genes, a complete new chromosome, is created. It is as though each of the forty-eight chromosomes had split along its length.

As cell-division proceeds, the cell nucleus breaks up and reforms as two nuclei. In achieving this the two "halves" of each chromosome pull themselves apart, one set going to each of the new nuclei being formed. The parent cell is re-created in the birth of its two daughter cells.

In this way each daughter cell comes to possess the same number of chromosomes (forty-eight) as did the original cell and, moreover, each daughter cell has the very same number and kind of genes as did the cell from which it arose.

And this is only the beginning of the story, for the process of cell-division continues until the whole of the living body has been built. Every cell of the developed individual will, disregarding the inevitable occasional accident, come to contain every chromosome and every gene that was present in the original fertilized egg.

As development proceeds the individual, to begin with a single fertilized egg and

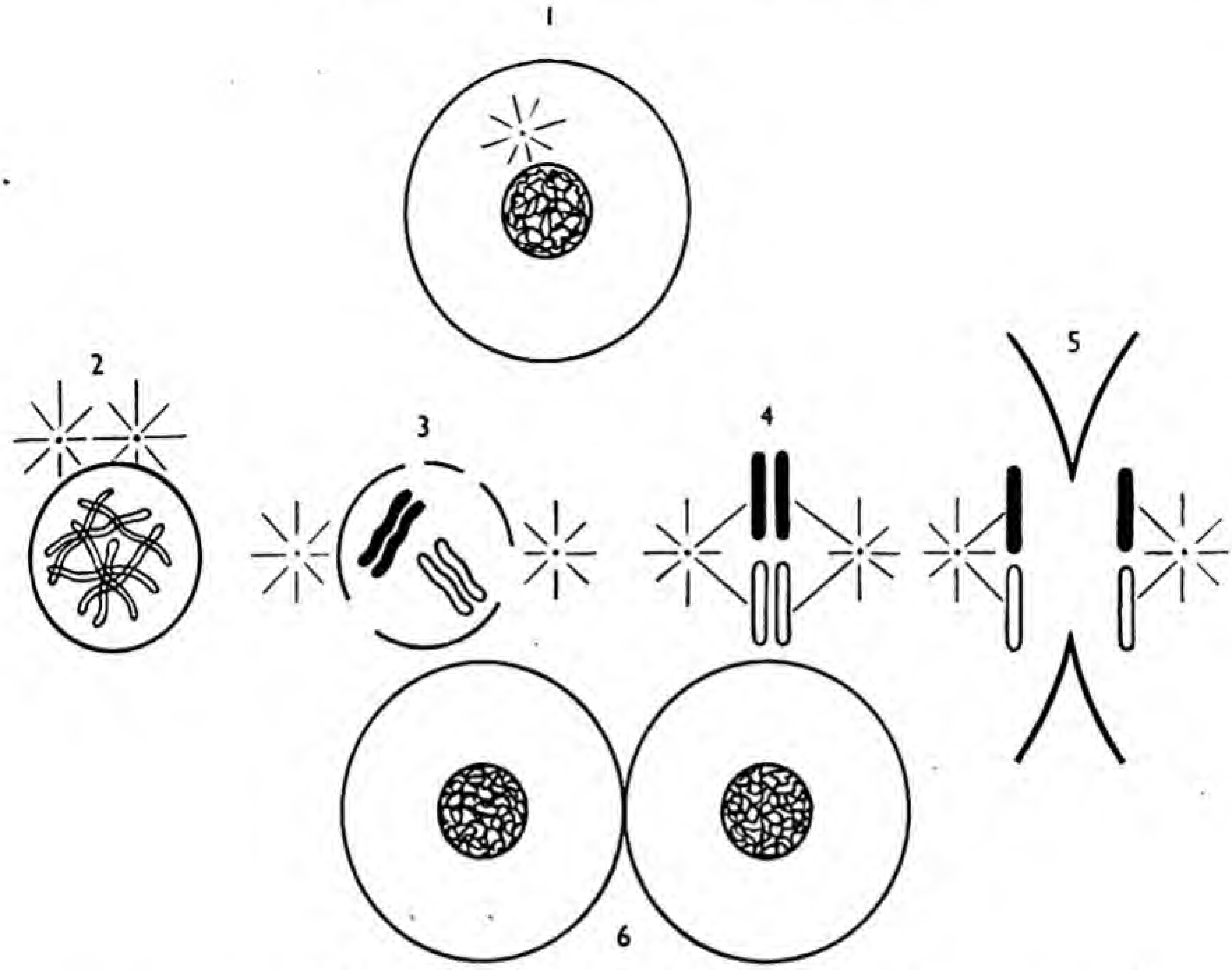


FIG. 1. CELL DIVISION OR MITOSIS

1. The typical cell with its cell walls enclosing cytoplasm (living stuff). The nucleus with its wall encloses the genetic material, the chromosomes. The centrosome lies outside the nucleus and acts as the centre of dynamic activity during cell division.

2. (The nucleus only.) The centrosome has divided into two. The genes have already duplicated themselves so that the chromosomes appear to have split along their lengths and are shortening and thickening.

3. The two daughter centrosomes have moved apart. The chromosomes (two only are represented) are a pair of homologous chromosomes, one, the solid one, having been derived from the father, the other, the outlined one, from the mother. The nuclear wall is dissolving.

4. The chromosomes have moved to occupy positions on the equator of the cell. Lines from the centrosomes are attached to them.

5. Each original chromosome and its duplicate are pulled apart and begin to become incorporated in the nucleus of a daughter cell. The cell itself is becoming pinched and is about to divide.

6. Two daughter cells result, each with the same number of chromosomes and the same number and kind of genes as the original cell contained.

then as the result of cell-division a mass of cells like a blackberry, begins to become differentiated. Different groups of cells become set apart for the later discharging of special functions; the head, the limbs, the internal organs and all the rest begin to take shape. The position of the cell groups in the embryo seems to determine which potentialities in the genes come into play; the regionalization leads to the specialized developments, of which the end results are particular aspects of flesh and blood, bone and hair, hand and feet, brain and ear, etc. Thus although every part and every cell has the same gene material, it depends on the media and circumstances

as to which become active in "growth"—as to which potentialities are being translated into living material. Hence skin, muscle, bone, eye, foot, brain, etc., are produced only where they are needed. The genes that predetermine eye colour, for example, will become active only in the eye cells, never in the cells of the foot, although they exist there as in every cell.

In earlier days it was taught that lying behind a particular inherited character—blue eye colour, for example—and related to it casually was a particular gene—the gene for blue eye colour. But now it is known that this is not so. No finished character is produced by one single gene, but results from the interaction and combined action of many genes, and a change in any one of these may result in a change in the quantity or quality of the end result. In any given case certain of these co-operating genes are more important than the others, and some may be essential whilst others are merely or mainly quantitative in their effects. Furthermore, it is now known that many individual genes affect more than one character in its development. The gene for blue eye colour affects many more characters than this, but since this is its chief or most obvious effect it gives its name to the gene.

It is also to be noted that the effect apparently due to a particular gene or genes can be produced only when the environment is propitious. Genes do not function in a vacuum, and the individual is not to be considered apart from his external world. The changes in the effects of genes caused by environmental differences are usually of a kind likely to help the individual to adapt himself to the environment. Genes have been retained in the previous process of natural selection which seem capable of permitting or effecting useful modifications in the growing creature when the environment would otherwise be unfavourable to its welfare.

The Nature of the Genic Action

There is, as yet, no exact knowledge of the nature of the ways in which the gene exerts its influence upon the processes of development. But as most of the active materials of the cell itself and also the genes themselves are known to consist wholly or largely of proteins, and since all enzymes are partly at least proteins, and since every chemical change occurring in the cell appears to take place only when some specific enzyme is present, it seems highly probable that the primary products of the genes are enzymes and that each of these different enzymes has its own special part to play in growth. Indeed, the growth of the whole organism is to be regarded as the complicated outcome of the process of gene duplication, and if we could but understand the latter we should come to understand the former. We know that the duplication of a gene, including the duplication of its own variations, would seem to be due to the ability of each element of the gene to attract to itself materials like unto itself and present but uncombined in the surrounding medium.

Mutation

A gene can undergo a change in its own internal organization. Such a change is known as mutation. The resultant gene, a mutant gene, affects the same developmental processes as did the gene from which it arose, but in a different way, so that a change in the character of the growing thing results. These changes may be for the better or for the worse. If, for example, the gene which "accounts for" the normal ability of blood to clot when exposed to the air mutates, the gene for hæmophilia may result.

Such mutation ordinarily affects but one gene at a time, and even though there are two such genes (maternally and paternally derived) in the cell only one of these two undergoes alteration. Which gene in the whole genotype it is that will mutate cannot be predicted. The event that produces the mutation is therefore a minutely localized one.

The cause of mutation is believed to be an accidental individual molecular or submolecular collision occurring in the course of thermal agitation. We know that when temperature rises the speed of molecular movements increases and with it the number of collisions and mutations. It was discovered too that, just as X-rays and some

other forms of radiation can be used to increase the frequency of molecular collisions, so does their use on living things increase the frequency of mutations. Indeed, the number of mutations occurring in experiments with X-rays is roughly proportional to the number of physical hits or collisions known to be caused by the radiation. Hence the inference that molecular collisions are the cause of mutation in genes.

Normally, mutations occur very rarely indeed: the chances are all against a gene undergoing a sudden change. This is just as well, otherwise living creatures would develop eccentric characteristics, most of them harmful, more quickly than the processes of natural selection could eliminate them.

Mutation being a matter of chance, the great majority of mutant genes must disturb an established equilibrium between a species and its environment and must therefore be detrimental in their effect. On the other hand, if a mutation chances to be useful to the creature, there is time for the processes of selection and survival to retain the new feature. Both the fact of comparative stability and the fact of occasional mutation are useful to life as a whole, for without relative stability there would be chaos in creation and without occasional mutations there would be no evolutionary progress. The mutant gene is the raw material of evolution.

Evolution is not primarily purposeful, nor are life processes adaptive except as the result of selection.

Mutant genes producing very marked changes tend to be more detrimental than do those whose effects on development are slight. It is among the latter that are to be met those whose action is found to be advantageous and which tend to replace the original genes in the germplasm of the stock. This is the result of the fact, of course, that the individuals so advantaged flourish and contribute more than the average share of progeny to the following generations.

The Gene and the Origin of Life

It is not improbable that the first living thing to appear on this earth was a gene with the power to organize the appropriate organic matter present in its immediate environment into another gene like itself. These earliest genes, mutating, would produce new genes, and so genetic variety would make its dramatic appearance. Then attachments would arise whereby "bundles" or "clusters" of genes would be formed and protoplasm would evolve, and the single-celled individual would appear as the forerunner of all the living forms that have lived and are living now (see Chapter XIV). It is not impossible that the viruses only recently discovered are but instances of life in its earliest single gene stage, and that the bacteria are representative of the early stage when aggregates of genes surrounded themselves with protoplasm.

The Significance of Fertilization

Let us look now at what happens when an individual life begins.

Conception, the creation of a new individual, consists essentially in the bringing together of two sets of genes—of the shuffling of the potentialities of the present stocks. One set enters the fertilized egg by way of the sperm, the other resides in the chromosomes of the nucleus of the egg itself.

The combination of these two sets of chromosomes brings together two genes of every sort of gene present in the parental stock to form the genetic constitution (or genotype as it is called) of the offspring. Hence we see that every individual has two genes for one function, one being derived from each parent. Genes, therefore, exist in pairs.

Now in any pair the genes may be alike in the sense of being normal. If so, the individual is said to be homozygous (that is, the "same yoked together") in respect of these genes. Or both genes of a pair may happen to be mutant genes. This, too, means that the individual is homozygous in respect of these genes.

Again, the genes of a pair may be unlike, one being the normal gene, the other a mutant gene. In this case the individual is called heterozygous ("different ones yoked together").

This distinction is most important because of the effect of the single normal gene

on the single mutant in the heterozygous individual, and this we must now discuss.

Dominance

In the individual who happens to be heterozygous in respect of one gene pair there are, as we have just seen, two genes, one the normal, the other the mutant. (It is usual to call such genes alleles, a handy term which means "another form": the normal and the mutant of a pair is each an allele of the other.) Each of these is capable of exerting its own particular and different influence upon the development of the same character. If the degree of expression of this character is thoroughly examined, it is often found that both genes have exerted their effects and that the resultant character is a compromise. But if the examination is superficial, it seems that one of the genes has produced its effect to the total exclusion of that of the other allele. One of the genes is dominant to the other, which is said to be recessive, or subordinate. Usually the normal gene is dominant to its mutant allele. For example, there is a mutation in a gene controlling the coat and eye colouring in many animals that has the effect of suppressing colour and, if colour is suppressed, an albino is produced. But this gene is itself almost completely suppressed in the presence of the normal gene. So if we have a couple of rabbits, for instance, one may be normal and homozygous (with two doses of the normal gene) and one heterozygous (with one of the normal and one of the mutant), but both will appear to be normal rabbits. But if we mate them and continue to inbreed the strain it may happen that we cross two heterozygotes. Then the offspring may be normal homozygous, heterozygous or mutant homozygous. And of these only the last will be albinos, but some of the others will have the mutant gene. Some will be pure-breeding normals, and they can be distinguished only by breeding experiments.

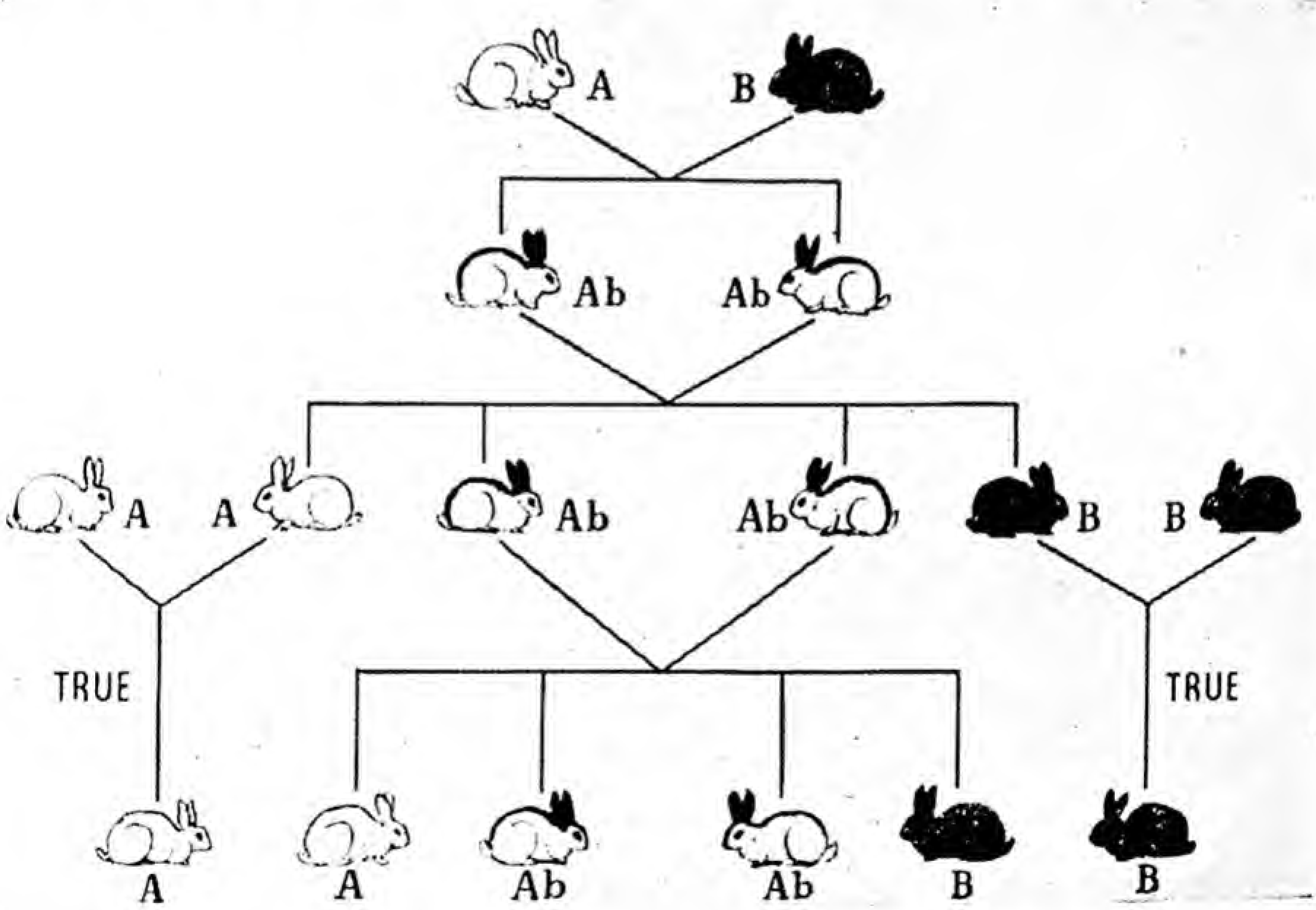


FIG. 2. MENDELIAN INHERITANCE IN RABBITS

This drawing shows how the characteristics of one parent may be recessive to those of the other, but will reappear according to certain definite rules in succeeding generations. (A) represents true brown, (B) true black, and (Ab) brown with black recessive.

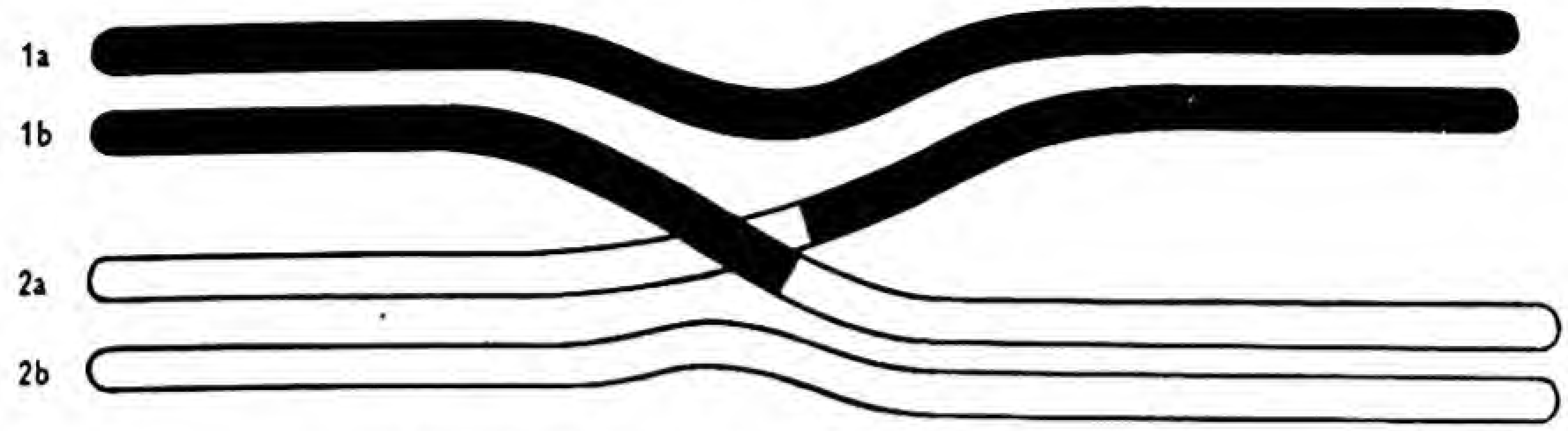


FIG. 3. CROSSING-OVER AT MEIOSIS

A tetrad. 1*a and* 1*b resulted from the gene duplication in the original chromosome of this pair contributed by the male parent,* 2*a and* 2*b from the same event in the maternally derived chromosome. There has been crossing over, mutual interchange of genetic material, between* 2*a and* 1*b.*

It is probable that the mutation of a gene usually results in the weakening of the gene's enzymatic action, which would make that gene less capable of functioning; and that dominance and recessivity really represent different grades of strength or effectiveness. It is to be expected that the genotype of any given species is one that has been produced through mutation and appraisal, and that it is that collection of genes which produces a healthy and effectively surviving stock. This would explain its stability which, as we have seen, is desirable. Thus, too, when one gene of a pair is normal and the other mutant, the normal gene is usually dominant to the other. If most mutant genes are recessive, it then becomes possible for an individual to be exceedingly heterozygous and yet exhibit the normal characterization.

Meiosis and Crossing-over

Offspring can differ from their parents, as we have seen, by possessing new mutations, which is rare, or by being homozygous or heterozygous where the parents were either both heterozygous or one normal and the other mutant homozygous. Now a much more common basis of variation is the interchange of corresponding pieces of chromosomes derived from the father and the mother, so that all the genes that are located in one particular chromosome need not always be inherited as a block. This interchange or crossing-over takes place in the formation of the eggs and spermatozoa. Let us look at how this crossing-over takes place. It has been stated that the nucleus of every cell of the body of the individual contains a double set of chromosomes, in man forty-eight, in the form of twenty-four pairs of homologous chromosomes, and that in the egg and the sperm, on the other hand, there are only twenty-four chromosomes, singles not pairs. This reduction in chromosome number occurs during the formation of the ripe egg and sperm as the result of the process of meiosis. During this each chromosome in the nucleus finds the one corresponding to itself that was originally derived from the other parent, and the two then entwine in lengthwise contact so that each gene comes to lie exactly alongside the same gene (or its allele) in the other chromosome. Some sort of specific attraction is mutually exerted by genes of like composition.

As a result of this coming together the two sets of chromosomes seem to have become reduced to one set. Then every gene duplicates itself so that each pair of chromosomes (looking like a single chromosome) becomes transformed into a group of four strands, a tetrad. Next, each two threads that are related by this doubling process tend to separate from the other two threads of the tetrad (shown diagrammatically in Fig. 3). But at some points two of these four threads, one derived from each of the original chromosomes, stick, break and reunite in such a way as to have interchanged corresponding segments of pater-

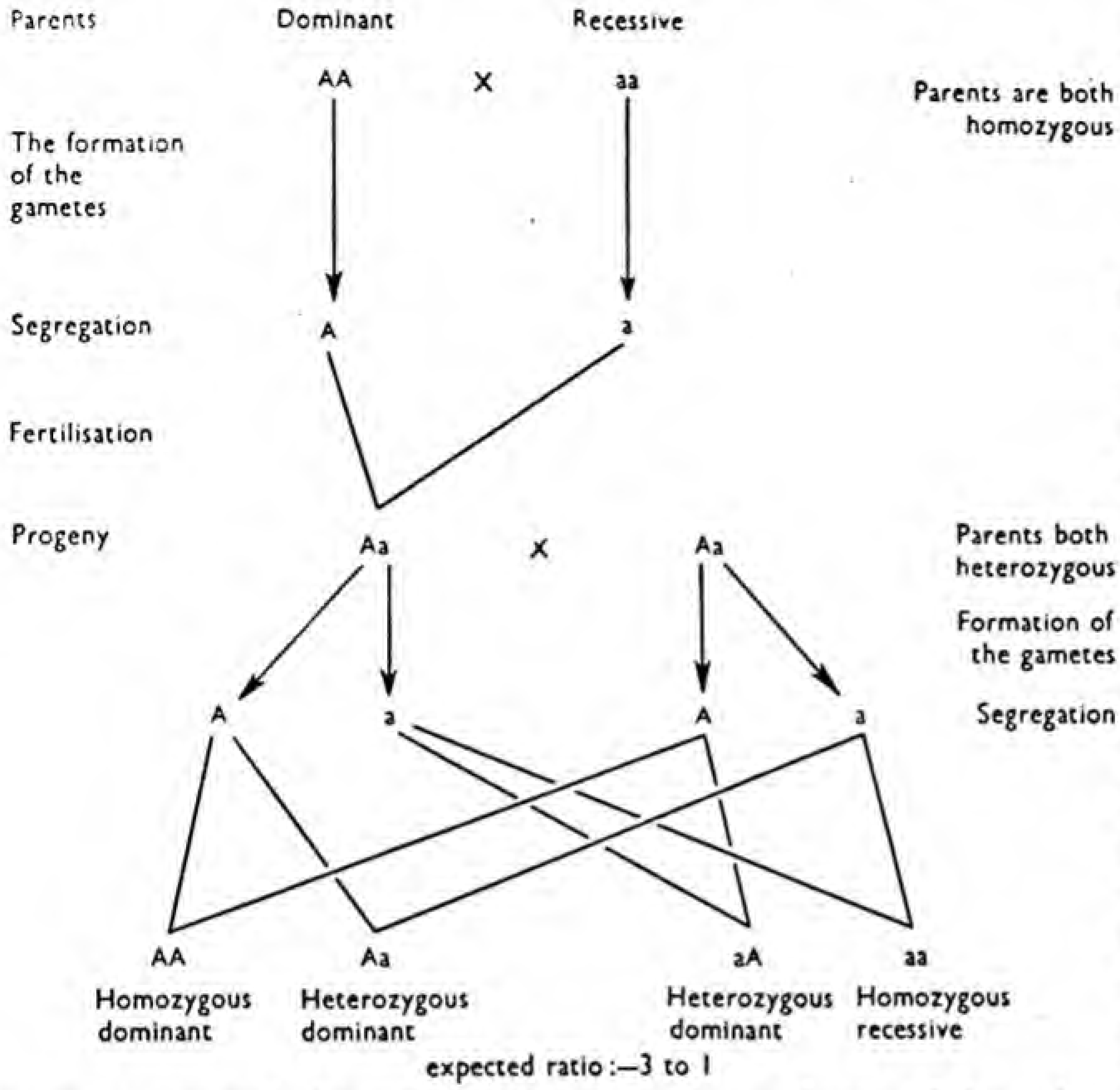


FIG. 4. THE INHERITANCE OF A PAIR OF CHARACTERS

nal and maternal threads. By this process of crossing-over each of the four threads still has a complete set of genes, but some of these can be of maternal and others of paternal origin. Previous associations of genes ABC and abc in the two original chromosomes respectively can, as the result of this crossing-over become disrupted and regrouped so—Abc, aBC, ABc, abC. Then each tetrad becomes divided into two doublets and these doublets are pulled apart. Then the two members of each doublet are pulled apart. By these two divisions four nuclei are formed and each of these has received just one chromosome derived from each tetrad. It is a matter of pure chance which of these chromosomes enters into a particular nucleus, and, as has been described, this one chromosome can be a combination of paternal and maternal genetic material. The outcome of this behaviour can be stated in the form of rather simple rules in the Mendelian laws.

Mendel's Laws

Mendel's first law states that of any pair of alleles which an individual possesses within its genotype, any given ripe egg or sperm produced will contain one or the other but not both. This is the law of segregation.

His second law refers to random assortment and independent segregation. If in any breeding experiment two or more pairs of genes are involved (e.g., AA, BB, Aa, Bb, aa, bb), each pair being resident in a separate pair of corresponding chromosomes, then the distribution of the members of one gene pair is influenced in no way by that of any of the others. As the result of the different possibilities of combination of these genes the new individual genotypes may be quite different from those in the parents. Thus if one parent is heterozygous for normal colour and a particular quality of hair, but the other is an albino, and has the recessive sort of hair as well, the offspring will have all the possibilities shown in Fig. 4 above, and in general it is often the case that a particular *combination* of characters is much more useful than any one taken singly. An arctic hare wants a thick coat and also a white one. "Thick and brown" would be too conspicuous, "thin and white" not warm enough.

Linkage

Mendel's first law remains unshaken by all the amazing advances that have taken place in our knowledge of organic inheritance. But it is now known that the second law holds only when the genes being considered reside in different chromosomes (as above). If they should reside in the members of the same pair of corresponding chromosomes then crossing-over and the mutual interchange of genetic material disturbs the law.

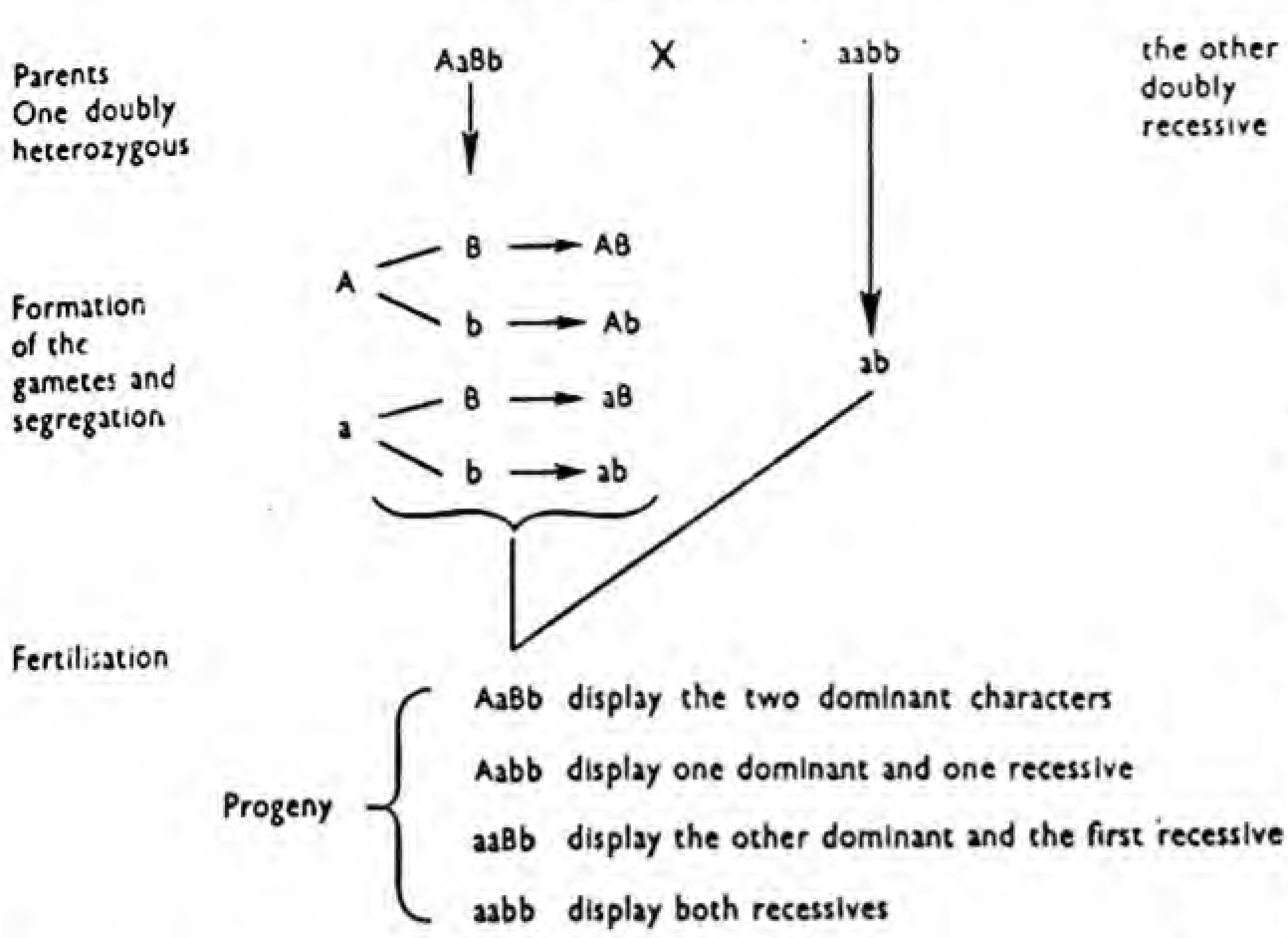


FIG. 5. THE INHERITANCE OF TWO PAIRS OF CHARACTERS

The pairs are on different chromosomes, so there is no linkage.

The genes resident in one and the same chromosome will remain linked in transmission, so long as the chromosome itself preserves its physical integrity. Crossing-over between two chromosomes with identical gene content is of no account, since what a chromosome loses it gains in this mutual interchange. It is when different alleles of different genes are present in the two members of a chromosome pair that this crossing-over can destroy this linkage.

Frequency of Crossings-Over

If this crossing-over can occur with equal ease at any point in the length of the chromosome then the closer together two genes lie the less frequent will crossing-over be between them; the farther apart, the more frequent. Thus by making a study of the frequency of new combinations by any two pairs of linked genes it becomes possible to make a map of the chromosome showing the position of the genes in their relative positions in the length of the chromosome. Crossing-over is a device that has become elaborated to give recombination of genes resident in one and the same chromosome. Quite a low frequency of crossing-over is sufficient to provide new phenotypes for appraisal.

Sex-Linkage

Sex is an hereditary character which obeys Mendel's first law of segregation. In man the female is homozygous for the genes for sex, and these reside in a pair of chromosomes known as the Xs. By segregation all her eggs receive one X. The male is heterozygous, having but one X carrying the very same sex-determining genes as do the Xs of the female. The X of the male has a partner, the Y chromosome, which is unlike the X in respect of its gene content. Part of the Y is homologous to the X, the rest is not. By segregation half of the spermatozoa produced by the male will receive the X, the other half the Y. An egg fertilized by an X sperm yields

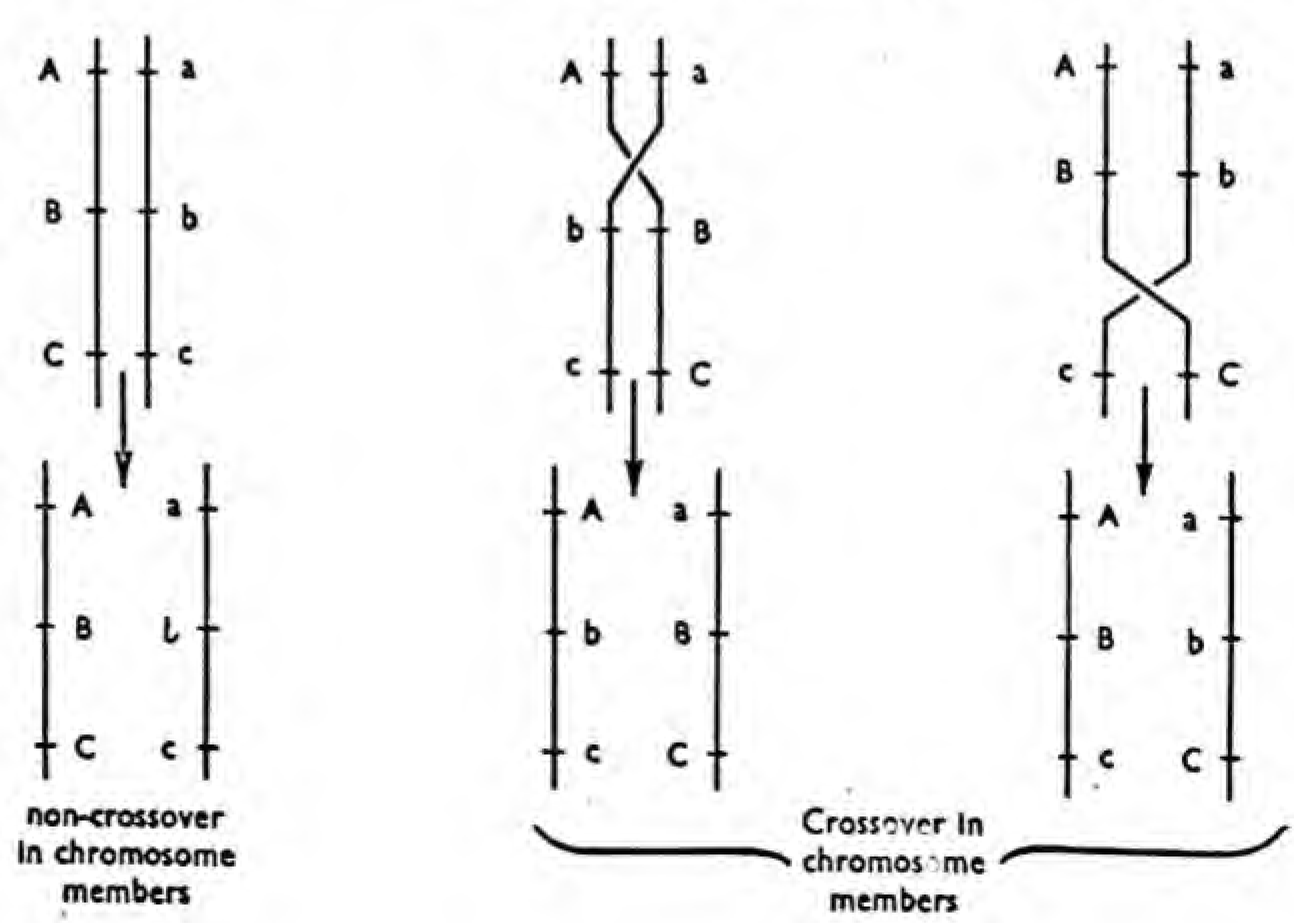


FIG. 6.
THE RESULTS OF CROSSING-OVER

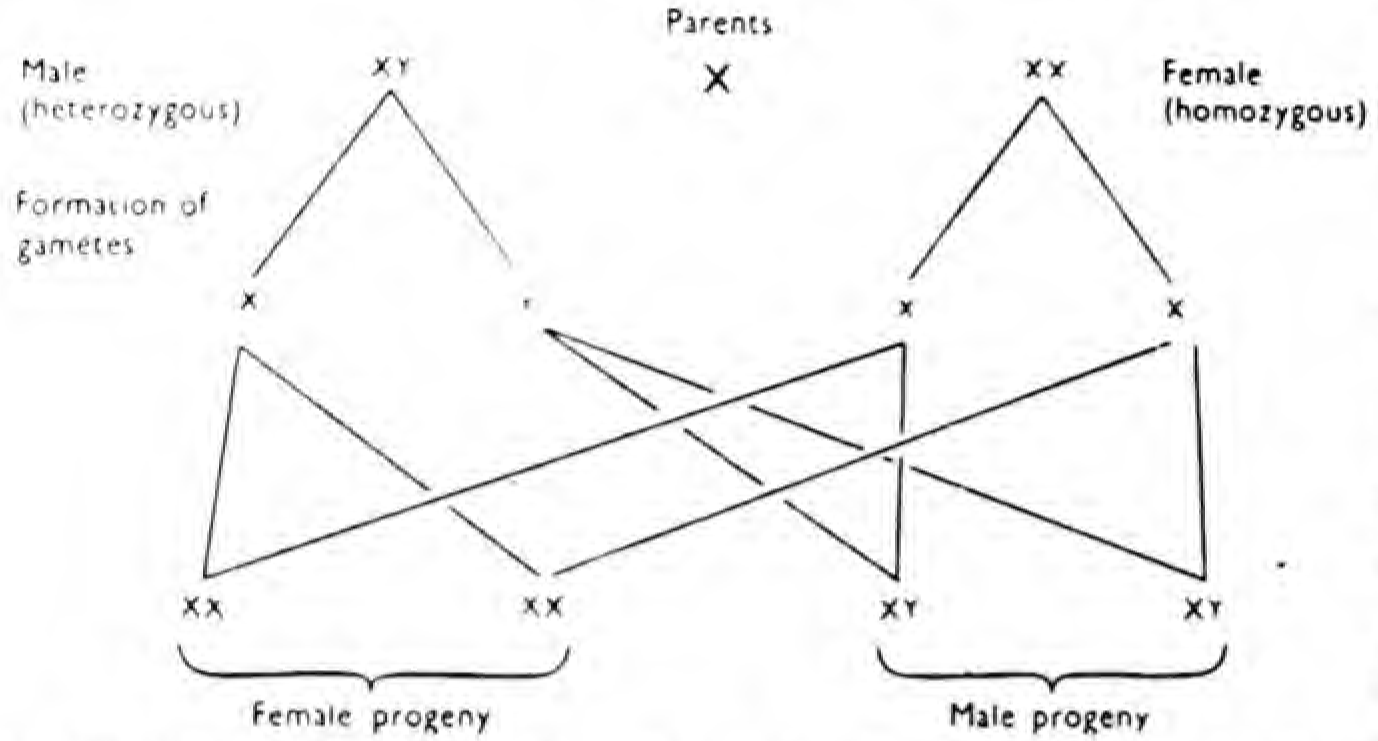


FIG. 7. HOW SEX IS DETERMINED BY THE X AND Y CHROMOSOMES

an XX individual, a female; an egg fertilized by the Y sperm will yield an XY individual, a male. In some animals the female is XY, the male XX.

Because of this difference between the sexes in respect of chromosome content it follows that characters dependent on genes in the X chromosome other than those concerned with sex determination will be linked with sex in their transmission. But there can be no crossing-over between the genes present in that section of the X missing in the Y and the sex-determining genes. They are completely sex-linked. Such completely sex-linked characters are peculiar in that, since there is no corresponding section of the Y containing normal genes, they will always be displayed in the male even though the gene is recessive. In the female, however, such a recessive character will appear only if the corresponding recessive gene is present in the homozygous state, present in both the Xs.

The Progeny Test

The genotype of an individual is revealed by his phenotype—the sum of the various characters he *shows;* but only imperfectly, since the latter may present little or no evidence of the numbers and kinds of recessive genes that are included in the former. The individual is not to be assessed genetically so much by what he appears to be—the totality of his visible characters, as by what he produces—the totality of the characters of his offspring. If the progeny are sufficiently numerous, which they seldom if ever are, then the genetic variation among them is the true measure of the heterozygosity of the parent and can provide a more or less accurate knowledge of his genotype. The expectations concerning the number and kinds of phenotypical varieties based on different combinations of genes can be calculated if the genetic constitution of both parents is known, and it is always found that the actual ratios and the expected ratios agree to a surprising extent. But in a human or a "wild" population the genotypes of the parents are not known, and most individuals of such populations do not differ one from the other in respect of a few pairs of genes, they are heterozygous in respect of hundreds.

It has been stated that mutation is infrequent. It does occur, however, and in any population every gene has a certain frequency rate. Thus, if a normal gene has, through mutation, yielded a mutant gene corresponding to a disadvantageous character, it is safe to assume that the individuals

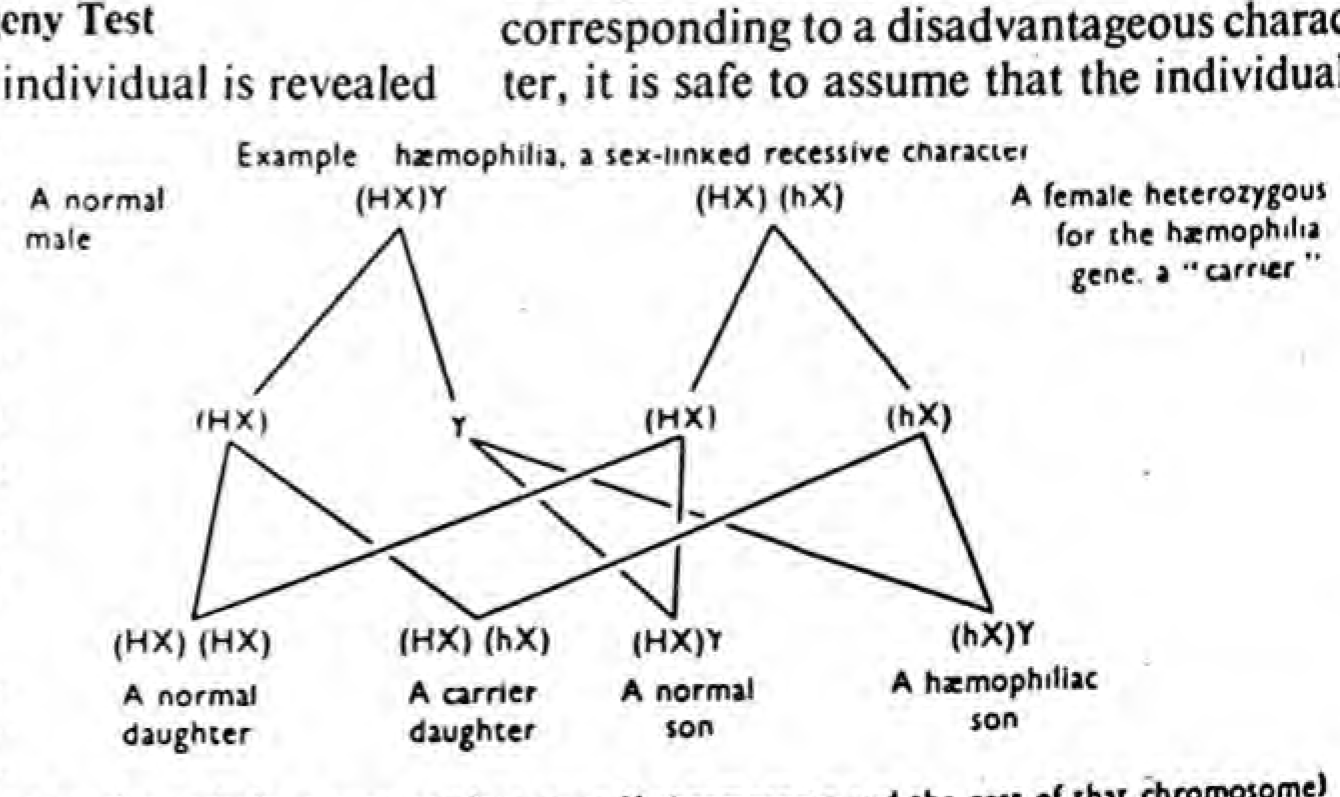


FIG. 8. THE INHERITANCE OF A SEX-LINKED CHARACTER

(A bracket includes a gene resident in an X-chromosome and the rest of that chromosome)

exhibiting this character and carrying this gene would tend to become eliminated. Nevertheless, fresh mutation could again yield the same mutant and undesirable gene. Two processes would be operating; the inception by mutation of an undesirable character and the elimination of the individuals exhibiting this character and its gene.

It seems that there is a correlation between these two processes and that an equilibrium is reached so that the gene is eliminated by natural selection as fast as it arises by mutation. The less disadvantageous on the average a mutant gene is, the slower is its elimination, and consequently the higher is the frequency of occurrence when it attains an equilibrium. Similarly, mutant genes conferring an advantage will tend to accumulate passively, as well as to multiply actively, until they become established in the place of the normal genes they replace.

Between the individual and its external world it is essential that there shall be established a harmonious interrelationship. The total set of characters shown in the individual (the phenotype) must be such as to allow him to flourish in the conditions and circumstances of the habitat; the habitat must be such as to supply and satisfy the needs of the individual. Just as a changed phenotype based on a changed genotype can destroy this harmony, so also, of course, can changes of sufficient magnitude, and beyond the adaptive capacities of the individual in the environment itself. Should such changes occur then the equilibrium values become different and some genes and gene combinations become more, and others less, advantageous than before. So it is that in different circumstances different genes through selection spread through a population to achieve that almost one-hundred per cent frequency which is known as normality.

Test Yourself

1. The characters of living organisms may be grouped under two headings. What are they?
2. How do we know that the egg and spermatozoon, which are the beginning of a new organism, contribute equally in their hereditary influence on the new organism?
3. How does every individual cell of a complicated organism, built up from myriads of cells, come to contain every chromosome and every gene present in the original fertilized egg?
4. What is a probable explanation of the way in which genes act?
5. What is a "mutation"?
6. What happens in meiosis and what is the importance of this process in heredity?
7. What are Mendel's two Laws? Are these laws known still to hold true in the light of modern advances in our knowledge of heredity?
8. Explain sex as an hereditary character.

Answers will be found at the end of the book.

HUNGRY YOUNGSTER

Young animals grow very much faster than they do when they are older. Therefore they require a very great deal of food in the early part of their lives. This voracious young starling exemplifies the eager hunger of a young animal. It feeds on grubs and caterpillars.

CHAPTER XIII

DEVELOPMENT AND GROWTH

As has been previously explained, the process of fertilization consists of the union of two kinds of sex-cells or gametes—the ovum of the female and the spermatozoon of the male—whilst the term development signifies the resultant changes that take place from the moment the egg is fertilized until maturity is attained. The male element has the effect of stimulating into activity the egg which on fertilization divides first into two, then into four, eight, sixteen and so on, until the embryo is fully formed.

With the exception of some of the most lowly forms of life, every living creature is developed from an egg. Even plants have egg cells. The highest animals, which produce living young, carry eggs, their development taking place at an early stage in the oviduct of the female and later in the uterus.

Some egg-laying animals are hatched in the almost perfect state, whilst others emerge from the egg only partly developed, or in a larval stage bearing little or no resemblance to their parents. Most birds and reptiles fall in the former class, even though they may differ from the adult in the size and texture of certain features. The latter class embraces some fishes, amphibians, crustaceans, insects, etc., and these, as a rule, differ completely in their appearance from the adult. Some larval forms, those of the eel, crawfish and various other creatures, are so wholly unlike the parental form that, although known for centuries, their true identities have been discovered in only recent times. Eggs may be surrounded by a hard, or comparatively hard shell, or may be enclosed in a tough or extremely fragile membrane.

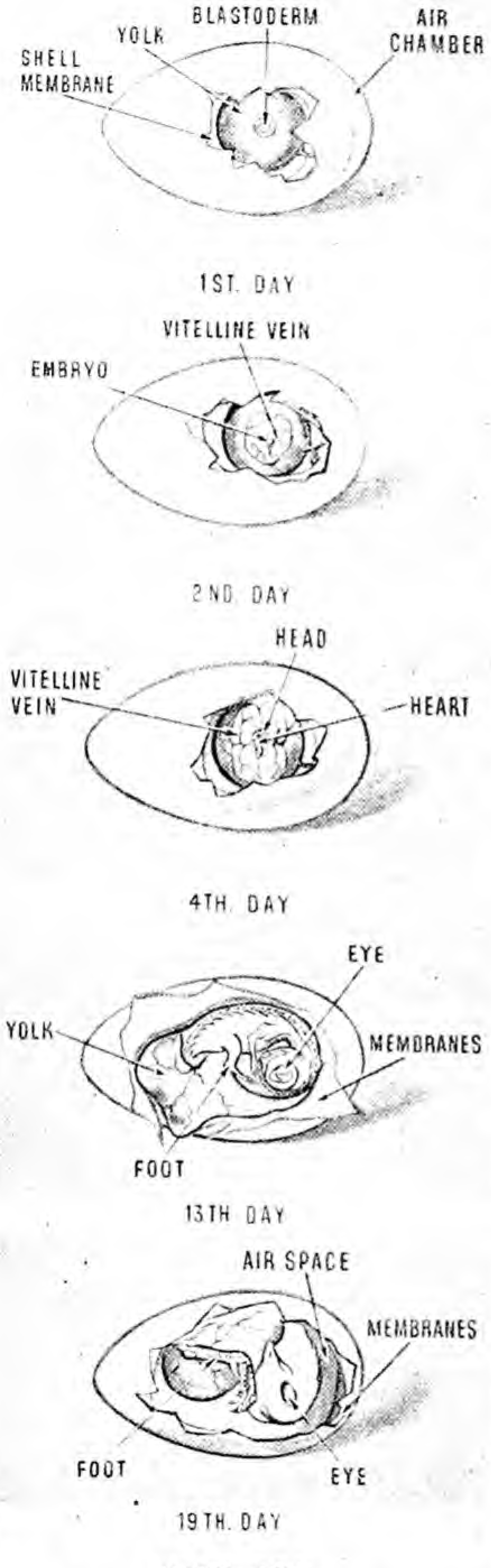
Let us examine a typical hard-shelled egg, such as that of a hen, and consider its development after fertilization. A section of the egg divided lengthways reveals the white—which in the raw state is not white but a glassy, translucent liquid—and the yolk, the part that supplies food for the developing animal. On one side of the yolk is a small spot, formed of protoplasm, which after the fertilization and incubation of the egg will develop into the chick. This "living spot"—the embryo—absorbs the nutritive material provided by the yolk, which consists mainly of fatty food substances, rich in vitamins. The white is also a larder, being formed of protein and water.

The yolk floats in the middle of the white and retains its position by being tethered by rope-like filaments to the shell's inner coating. As a result of this contrivance, the yolk-ball swings about in such a manner that, even when the egg is rolled over, the developing chick remains uppermost and thus in close proximity to its mother's warm body. The hard shell of the egg is composed of lime and, being porous, enables the developing animal to obtain the necessary oxygen for breathing purposes by absorption from the outside through the shell. The beak of the chick, prior to hatching, develops a hard protruberance or egg-tooth, and when the time comes for the creature to explore the world it frees itself by hammering at the shell with this weapon. The hard outer covering cracks, the chick crawls out and the egg-tooth, serving no further useful purpose, falls off.

Evolutionary Landmark

Biologically, the shelled egg marks an important step in the upward and forward trend of evolution, for it implies many advantages for the creature lodged in it. The number of hard-shelled eggs laid is usually dictated by their size in relation to that of the parent. Thus among birds the kiwi, which lays in proportion to its size the largest egg, seldom lays more than one.

The great majority of animals so produced step from the broken shell well equipped to pick up a living. Though it may be unsafe to dogmatize just when the shelled egg first had its being, it was certainly an established institution with the development



HEN'S EGG
Five stages of development.

of certain land molluscs. Some large tropical snails produce eggs superior in size and strength to those of many birds and these, snugly hidden in the soil, stand a vastly better chance of survival than do the minute, soft, gelatinous eggs of their relative, the oyster, which are dispersed by the million, in a haphazard manner, into a hungry world. The majority of creatures laying hard-shelled eggs can afford to lay but a few, confident that most, if not all, will stand a fair chance of survival.

Only two mammals lay eggs—the duck-billed platypus of Australia and the echidna or porcupine ant-eater of the same continent and New Guinea. These may be regarded as animals which bridge the gap between the ancestral reptile stock and the mammals.

Development of a Frog

Mention has already been made of animals that leave the egg in an embryonic or larval form, differing entirely from their parents in appearance. Let us trace the early development of the common frog, which in its early stages evinces an affinity with the fishes by passing through a gill-breathing larval stage.

The female frog abandons her rounded eggs, enclosed in a gelatinous envelope—a provision against frost—in a pond in the early spring. The egg is spherical with a black spot—the living spot—in the middle of more or less transparent, jelly-like substance which corresponds to the white of a hen's egg. The black spot is on the top of a small amount of yolk (which is white), the quantity of this food-store being meagre.

A few days after the eggs have been laid and fertilized, the black spot changes form and becomes elongated and horse-shoe shaped. The head begins to take shape and the presence of external gills becomes visible. When liberated, which happens about ten days after the egg has been laid, the larval frog, or tadpole, has a large head and long tail, breathes by gills and is limbless.

Gradually, the gills disappear to be replaced by lungs, limbs are produced, the hind legs first, followed by the front ones, and lastly the tail is absorbed. At the end

YOUNG OF EGG-LAYING MAMMAL

The young ones of the duck-billed platypus emerge from their eggs in a very helpless state. Three are shown here in the nest near a river or stream. The young are hatched by the heat of the mother's body and fed by milk, which exudes from a number of pores on her skin.

of two or three months—a period varying according to the temperature of the water—the tadpole, which during its aquatic life has fed on algae and decaying matter, both animal and vegetable, will have metamorphosed into a frog.

The larva of a Mexican salamander, known by the name of axolotl, is remarkable in that, in certain lakes it inhabits, it may spend the whole of its existence in the imperfect form, breeding in that condition. It has been found that this Peter Pan of the animal world can be forced to grow up by being given a single meal of thyroid or pituitary gland. The axolotl is a creature with large external gills, fins on the back and tail and having, like all aquatic animals, no eyelids. Soon after being fed on thyroid or pituitary gland, its gills and fins disappear, eyelids are formed and the creature leaves the water transformed into a lung-breathing salamander.

The Brazilian paradoxical frog, although no larger than the common British species, is actually considerably smaller than its tadpoles. The latter attain an enormous size and were described by ancient writers as animals which had begun life as frogs but which eventually turned into fish.

In the fishes, there is usually a relation between the size of the egg and the development of the young on hatching. In those forms that produce large eggs the young usually emerge in a fully developed condition; where, however, they are small there may be a prolonged larval stage.

Examples of larval fishes include the newly hatched lung-fish, which are provided with long, feathery external gills and are very like the tadpoles of frogs and toads,

the eels, the flat-fish and the lampreys. The eel when it leaves the egg and starts on its long journey from the Sargasso Sea to European shores, is a transparent, leaf-shaped creature quite unlike the mature fish, with a very small head and no fins, and it is not until it is nearly three years old that its body attains a cylindrical form and bears any resemblance to its parents.

The eggs of that primitive fish, the lamprey, give rise to worm-like larvae, known as prides, which differ from the adult fish in having rudimentary eyes, buried beneath the skin, and horseshoe-shaped mouths, surrounded by fringed barbels forming strainers. Soon after hatching the prides select a suitable spot, where they dig vertical tubes in which they lie buried for a period of three or four years, before metamorphosing.

In the lower animals, the retention of a larval period for short or long periods is the rule rather than the exception. Insect larvae differ enormously in size, shape and length of time they take to develop into their perfect form. The eggs may be laid singly or in masses on plants, in the earth or in water. During development, the larvae shed their skins and in some cases with each moult become more like the adult. In other insects, the larvae, when they have attained their full size, secrete a tough covering and in this covering, cocoon, or chrysalis they rest and assume their final characters. When the transformation is complete, the covering splits and the insect emerges.

Larvae of Dragon-fly

Butterflies, moths and flies leave the egg in a wingless state in the form of caterpillars or grubs. The eggs are laid, in the case of butterflies and most moths, on plants that give the grubs the nourishment they require; in many flies they are deposited on decaying flesh. The ostentatious, sun-loving dragon-flies spend their early days in the larval state at the bottom of ponds or streams, when they fearlessly attack anything they can overpower, even quite large fish. The mouth-parts of the larva form a mask armed with a pair of sharp pincers, which can be projected a considerable distance and are employed to seize prey. When the larva, or nymph, is fully grown and is about to transform into a dragon-fly, it ceases to feed, climbs out of the water on to the stem of a plant and waits for the hard cuticle with which it is enveloped, to split, It then emerges a fully formed dragonfly.

The mayfly, before it dances for only a few hours on the water's surface, spends a lengthy period, often years, as an aquatic nymph. The fly's eggs are deposited in enormous numbers—sometimes as many as four thousand are laid by a single female—in the water. The larvae, which are herbivorous, usually burrow into the stream-bed as soon as they are hatched. At the time of year when the mayfly is due to make its appearance, the nymph rises to the surface, its back splits and from the hard cuticle which surrounds it a mayfly crawls out and takes to its wings.

Longest Larval Life

Perhaps most remarkable of all insect larvae are those of the North American seventeen-year cicada. The grubs of this creature spend exactly seventeen years underground, and when about to transform make their way to the surface by the million, simultaneously.

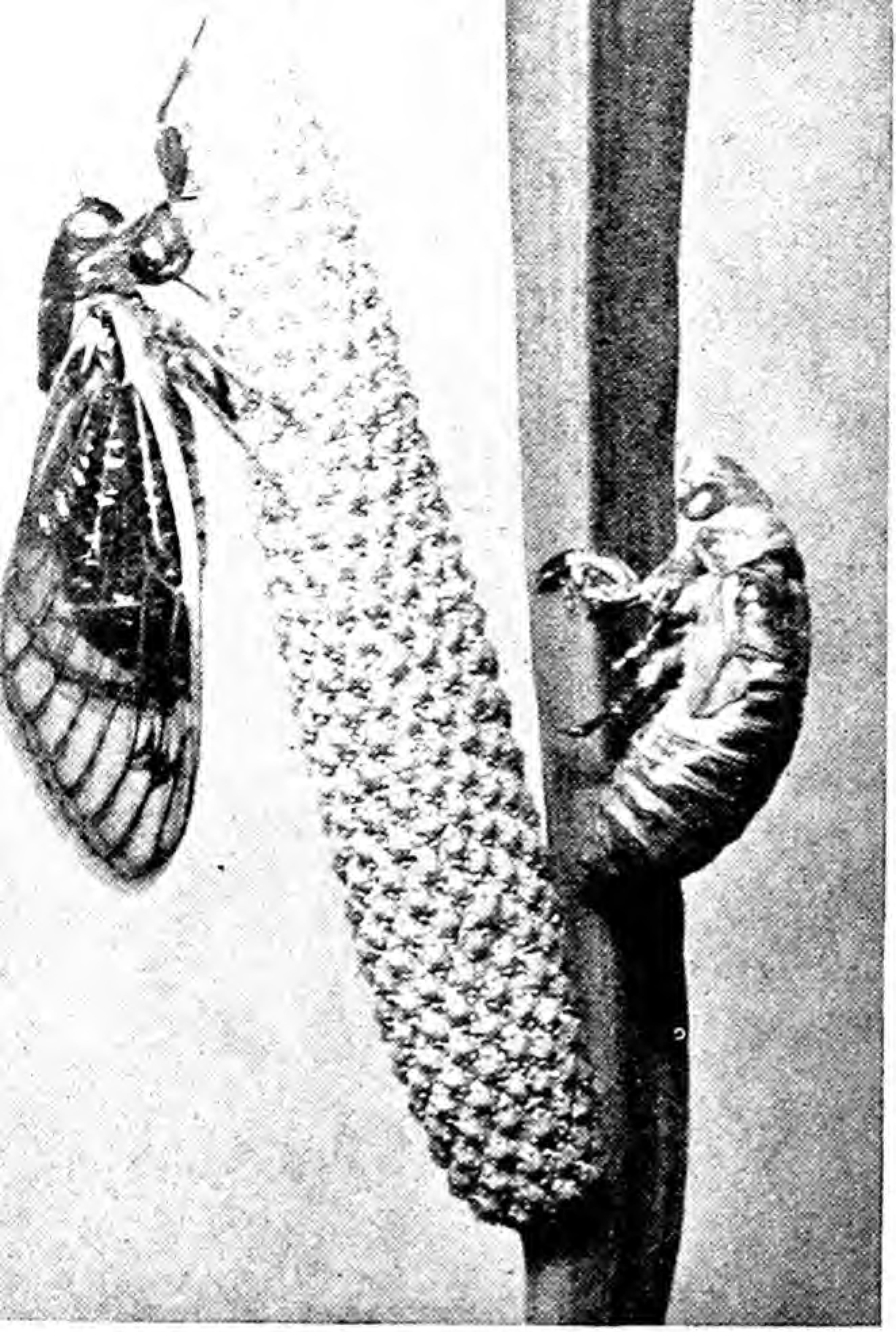
The sea surface is populated by a vast community of minute transparent larval creatures, collectively known as plankton. Many of these are the young of crustaceans, worms, molluscs, etc., which as a rule propel themselves through the water by means of numerous lashing hairs, or whips.

The larvae of crustaceans, such as crabs and crawfish, are grotesque-looking creatures, with enormous heads which are maintained in equilibrium by means of projecting spines. The sedentary barnacles, as a result of a study of their young, are now known to be crustaceans. When attached to a rock, and uncovered by water, the barnacle shows no active signs of life, but in its early stages it is free-swimming and in its make-up conforms to other infant crustaceans. The young barnacle leaves the egg as a minute pear-shaped animal with three pairs of appendages.

After passing through a series of moults, the body becomes enclosed in a loose

LLAMA MOTHER AND CHILD

Llamas are members of the camel tribe and are indigenous to South America. They are very strong and sure-footed and are used in mountainous districts as pack animals.



LONG LARVAL LIFE

The North American cicada spends seventeen years underground as a larva but only a few weeks as an adult. Here an adult has just emerged from its larval skin, leaving it clinging to a stem.

carapace, with eyes, feelers and six pairs of limbs. After spending a free-swimming existence, it fixes itself head downwards to a solid object by means of its feelers. The eyes then disappear and calcareous plates, which form the new and formidable armour of the adult, develop. The barnacle is an example of a comparatively low type of animal in which the adult condition constitutes a stage, not of development, but of degradation, or retrogression.

Travelling Backwards

Still more perfect examples of creatures which have turned back, after travelling far upon the road of evolution, are the ascidians or sea-squirts. These, when adult, may resemble plants and become encrusted on rocks or weed, or take the form of fleshy, flask-shaped creatures that remain anchored to solid objects. Some may live as single individuals, others may form colonies, but all agree in their relationship to the higher animals by spending their early lives as independent tadpole-like animals. They are then provided with a notochord, similar to that formed in every back-boned animal, a brain, an eye, a balancing organ, a mouth, a digestive system, a heart and a nervous system.

After swimming about for some time, by the aid of a long-finned tail, and leading a free and active life, the juvenile sea-squirt attaches itself to some fixed object and undergoes a course of degeneration, gradually losing its notochord and greatly reducing heart, brain and tail—all, in fact, except a few essential organs.

With a few exceptions, the number of young that an animal is capable of producing and raising is in the case of mammals determined largely by size. The small spiny mouse of Egypt can scarcely be said to have any childhood, since the creature from the age of a little over a month produces a family of about a dozen every three or four weeks.

Another very prolific mammal is that spiny, insectivorous inhabitant of Madagascar, the tenrec, which at frequent intervals produces a litter of twenty or more. The small opossums also have large families of about a dozen and these make their appearance at intervals, much as the chicks of certain birds hatch from the eggs and the fry of

viviparous fish are born by instalments.

In contrast to the mice, which launch a large family on the world more than a dozen times within the year, is the Australian "bear," or koala, which produces only a single young and breeds only in alternate years. The mammals that normally give birth to a single young include the apes and monkeys, the elephant, the whale, the various cattle, sheep, goats, horses, antelope, the giraffe, the camel, the rhinoceros, the hippopotamus, the tapir, the sloth, the ant-eater and the kangaroo.

Eggs of Birds

The number of eggs that a bird lays bears no relation to its size. The second largest of all living birds, the emu, may lay as many as eighteen, while the little crested swift is satisfied with a single egg. The smallest of birds, the humming birds, lay two to four eggs only, whilst such comparatively large forms as the mound birds and guinea fowl may deposit as many as twenty. The parasitic cuckoo of western countries lays about twenty eggs, each being placed one at a time in the nest of some other species of bird. Birds that lay but a single, or exceptionally two eggs, include forms differing in size, relationship and habits. They are the large kiwi, the penguins, the petrels, the flamingoes, the griffon vulture, the toucans and the diminutive sun birds.

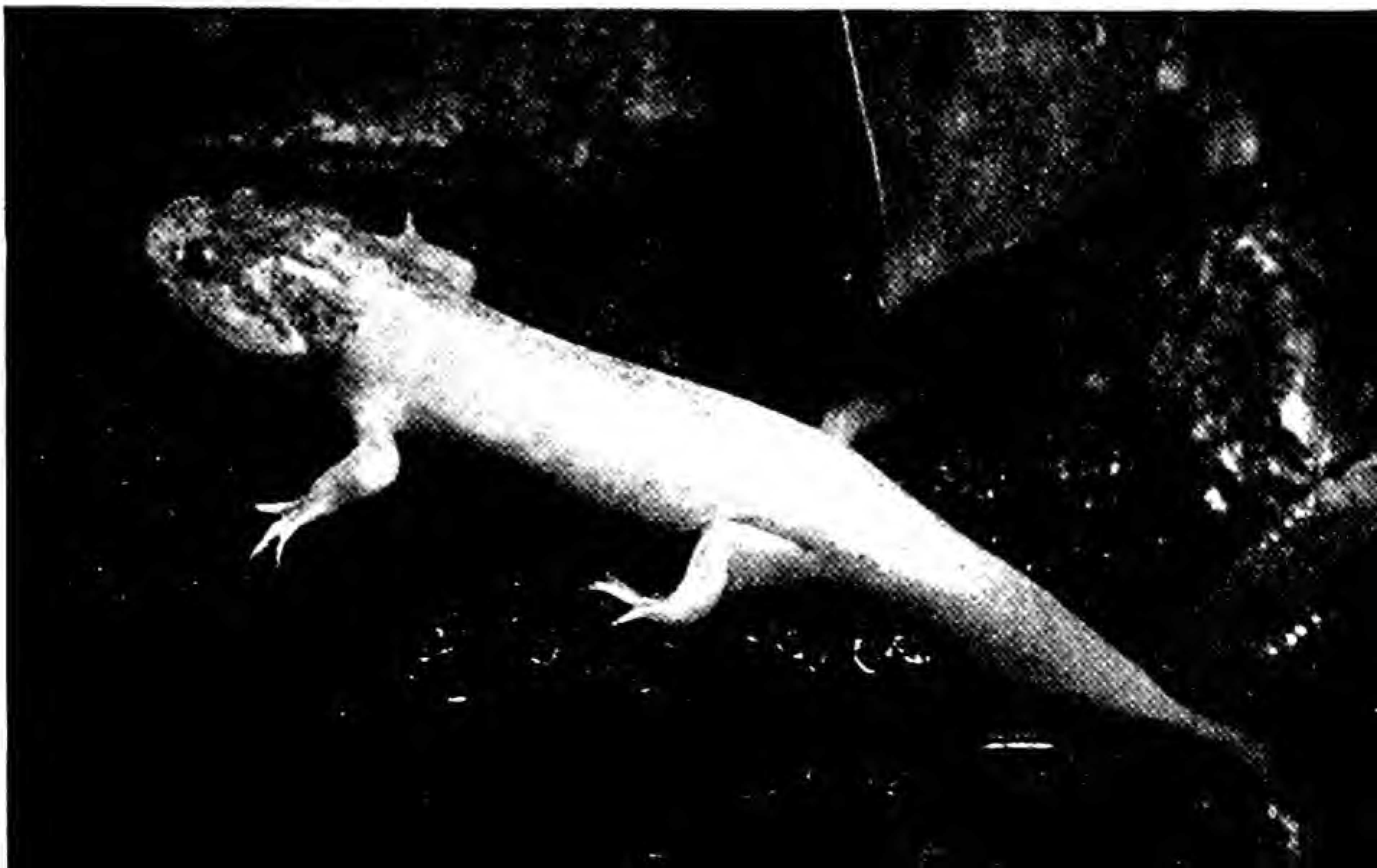
As will be discussed later, most birds show a lively responsibility in rearing their families and devoting themselves to the education of the chicks. In the cases where the young are helpless when they leave the egg, they may be many weeks acquiring strength and knowledge whereby to earn their own livelihood. Where, as in the case of the partridge, the chicks can scratch for themselves almost as soon as they are clear of the egg, and the family is a numerous one, the race will hold its own in spite of lack of parental support and guidance.

As regards reptiles, the number in the family varies between two and one hundred, the accepted method, with very few exceptions, being to abandon the eggs, or the young, in the case of viviparous species, in holes in the earth, sand or rotting vegetation.

Amphibians may lay five thousand or more eggs and leave them to their fate, or only a few, in which case the eggs, and

AMPHIBIAN FORM OF AXOLOTL

A semi-albino variety of the Mexican salamander Amblystoma tigrinum. *In its aquatic larval form it is known as an axolotl and has external gills and back and tail fins. In some waters it retains the larval form throughout life and even breeds in that condition.*

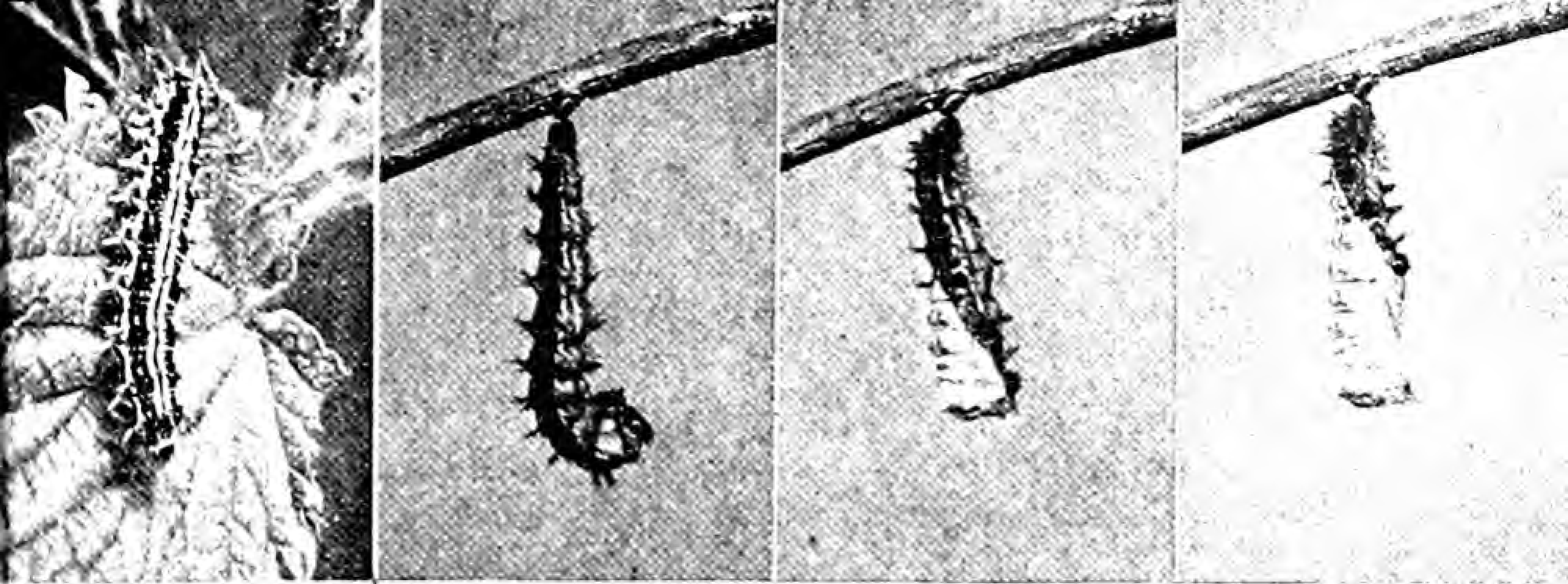


Metamorphosis of the small TORTOISESHELL BUTTERFLY

EGGS (MAGNIFIED)

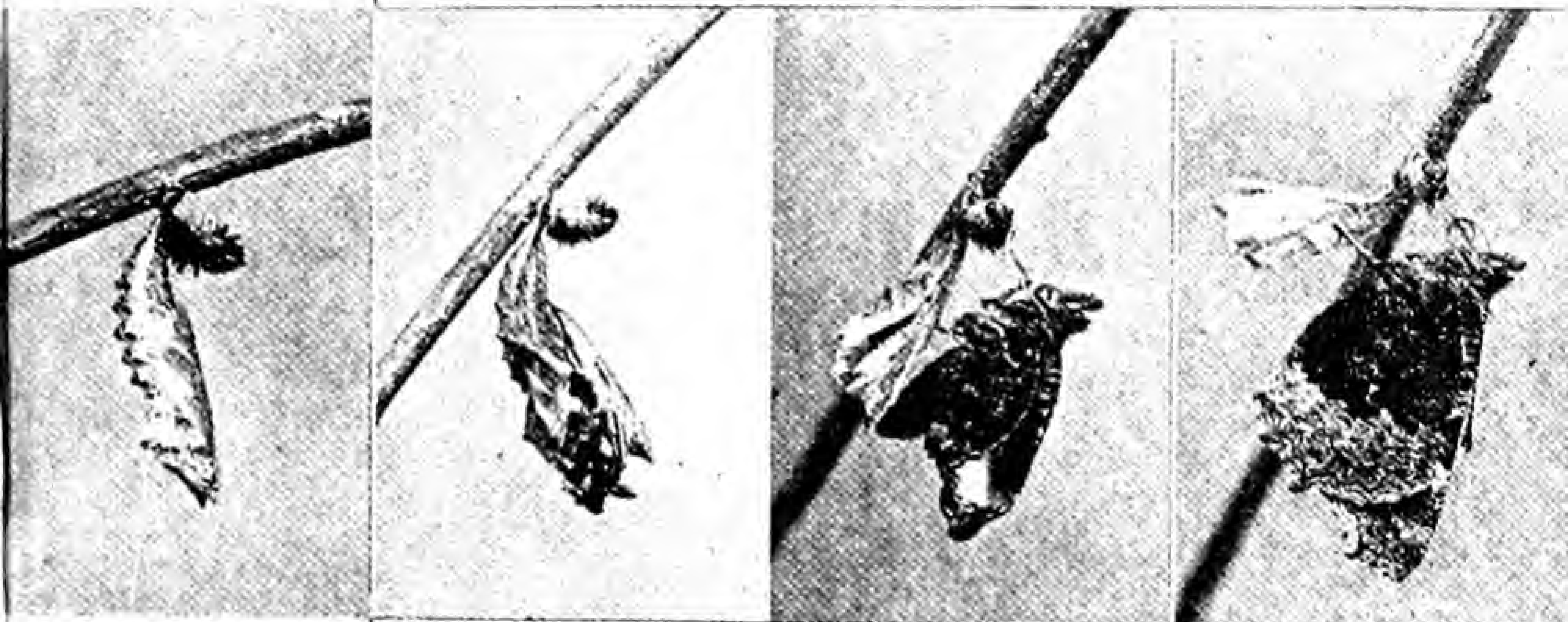
YOUNG LARVAE FEEDING

YOUNG LARVAE IN WEB (MAGNIFIED)



GROWN LARVA

THREE STAGES OF PUPATION



PUPA (CHRYSALIS)

BUTTERFLY EMERGING (THREE STAGES)

occasionally the tadpoles, are very carefully guarded by the parents.

Prodigality and its reverse is seen in the fishes. The world record is held by the ling with thirty million eggs. Other fish that lay very large numbers are the turbot, nine million, and the cod, seven million. Where the eggs are laid at or near the surface, and left to chance, or rather to the mercy of adverse winds, currents, temperature and a host of enemies, the waste is enormous and it has been calculated that in the case of the cod, less than one egg in every million actually survives to become a fully formed fish.

Oyster's Chances of Survival

Reckless wastage is the lot of the eggs and larvae of most invertebrates. In the case of the oyster, except where man has stepped in and reared the creatures artificially, only about a dozen of these molluscs attain maturity out of every two million eggs laid. On the oyster's eggs hatching, the larvae or spat are shot out of the shell into the water with considerable force and the two million baby oysters travel to the surface, resembling a smoke cloud. Their journey is indeed a perilous one. The surface of the water swarms with such enemies as the larvae of fish, crabs, lobsters and jellyfish all regarding the infant oyster as a delicacy. Should it run the gauntlet safely for forty-eight hours, it proceeds to sink to the bottom and if it finds suitable anchorage cements itself to the sea-bed.

As it grows, it enlarges its shell and accommodates its increasing girth by adding layer upon layer of oyster-cement to the outer edge of each shell. It grows at the rate of about half an inch in diameter a year for the first five years of its life, when it may be regarded as grown up. Even when adult, the oyster is at the mercy of starfish, sea urchins, crabs, octopuses, whelks and boring sponges. The starfish envelops the mollusc in its arms, each of which carries several hundreds of suckers, and exerts a pull which has been calculated at over ten pounds. At the same time, an acrid secretion is ejected between the oyster's valves.

The whelk attacks its fellow mollusc, penetrating its shell with its rasp-like tongue, whilst the boring sponge, which is able to tunnel limestone to a depth of

CHAMELEON DEPOSITING EGGS

Some species of chameleons lay eggs: others retain their eggs inside their bodies until the young ones are fully formed. This species may lay as many as forty eggs at a time.

ELEPHANT SEAL AND CUB

Some of the animals have returned to the aquatic life practised by their ancestors, though they retain the mammalian method of bearing their young alive. An elephant seal mother is shown with her cub. They get their name from the flexible trunk or proboscis.

several feet, makes short work of oyster shells, honeycombing them with a maze of galleries.

Child welfare in the wild depends largely upon the number in family. This rule applies to the mammals, if with less force than to animals lower in the scale of life.

Care of the Young

In mammals, with some exceptions, the care and upbringing of the young devolve solely upon the mother. In all apes, and most monkeys, the infant is nursed like one of our own kind. In the case of that diminutive little monkey, the marmoset, it is the father, however, who dutifully rocks the cradle. The male has the baby thrust upon him almost as soon as it is born, and only when its nourishment becomes imperative does its fickle mother take over, handing back the burden to her conscientious consort the moment her duties have been performed. The child is nursed, first in its father's arms, later resting on one hip and finally upon his back.

Arrived at this stage of development, its bulk and boisterous demeanour render its porterage an anything but enviable task, and when at the end of about three or four months the father divests himself of his offspring he does so, one imagines, with definite relief.

In mammals which are born in a helpless condition, the infants are nursed in a family which lives by itself. Where, however, as in the case of grazing animals such as antelope, which, in order to avoid their enemies, may have to move on at a moment's notice, the self-helpful young, differing little from the adult except in size, and possibly in coloration, associate with other families and, although fed by their own mothers, are protected by the largest and strongest males, who take charge of the community. These animals live in herds for their mutual protection.

The method of carrying the young about on the back or in an abdominal pouch, as in the case of the marsupials, is resorted to by a number of mammals. The kangaroo and the wallaby make perfect mothers, once their infant is safely tucked away in the pouch, but are not equal to the task of conveying them into the pocket. Recent observations show that the baby kangaroo's safe emplacement in the pouch is at best a very uncertain business. The new-born animal, not more than an inch in length, even in the case of the largest species, and bearing a superficial resemblance to a maggot rather

MATERNAL PROTECTIVE INSTINCT

The young mammal is born in a relatively helpless state when compared to the young of some of the lower forms of life. But maternal care reaches its highest expression in the mammals, and the mother not only feeds her young ones but also protects them from the dangers which they would encounter if they left her side. Most monkeys are devoted mothers.

than to a mammal, struggles on knees and elbows into the pouch, at considerable risk of wandering in the wrong direction and so perishing.

The mother is so witless as to have no idea of guiding her helpless infant's wanderings, so that its ultimate acquaintance with the milk supply and its hopes of thriving to maturity are great adventures. Once in the pouch, the baby kangaroo may remain there and look out on the world for at least six months. At the end of that period, it becomes an uncomfortable charge and is expelled, having outrun its mother's patience.

The Australian tree-opossums, like the kangaroos, and in fact all Australian animals, likewise spend their early infancy in the maternal pouch. But these opossums, six or more in number, when the pouch cannot accommodate them, all are carried on the maternal back, each baby opossum keeping its position by twisting its long prehensile tail round that of its parent.

Offspring of Bats

The bats, which are held by many authorities to be more closely related to the monkeys and lemurs than to any other animals, enter the world naked, save for a mere shoulder-cape of hair. The inverted position is its normal posture while suckling, when one of its mother's ample wings forms a cradle in which the baby rests. When its weight becomes oppressive, the infant is shifted over to the opposite wing and is later weaned on scraps of fruit, which it takes from the parental mouth.

Many aquatic mammals such as sea-lions, beavers and hippopotamuses, are "all at sea" in their early days and have to undergo a course of swimming lessons under maternal tutelage. The baby sea-lion, for instance, is pushed forcibly into the water by its mother who, until the youngster shows that it can be safely left unaccompanied, swims underneath her offspring. Should the baby show signs of distress, the parent supports her pupil on her back and makes for the shore.

The hippopotamus is another aquatic animal that does not take to the water from birth. The hundred-pound infant is carried into the water on its mother's back but is not submerged. So used to this riding is the very young hippopotamus that on one occasion at the London Zoo, when its parents had a serious difference of opinion in their pond and rose on their hind limbs, the infant obstinately retained its seat.

Some aquatic rodents are carried to the water in a remarkable fashion. The infant beaver, for instance, literally surf-rides on its mother's broad, flat tail, clinging to the fur of her back. The large South American coypu rat is accommodated in an equally striking fashion. A family of six babies cling to their mother's back—three a side—aiding her progress by vigorous strokes of their small webbed hind feet, so that the coypus when swimming *en famille* present the appearance of a miniature galleon under way.

In the shrews, the milk glands are situated adjacent to the mother's armpits. In the elephant shrew, so called because of its immensely long nose, its two babies ride side by side on its back, their trunks sloping over the maternal shoulders one on either side of the parent's face.

The young of the echidna are hatched from eggs in a kangaroo-like pouch, the infant chipping the shell of the egg by means of an egg-tooth—an enamel spur fitted at the end of the snout. The duck-billed platypus lays two or three eggs, each about the size of a pigeon's, in a grass-lined chamber near the water's edge, which may be forty feet from the entrance. On hatching, the babies are blind and naked: the beak is fleshy, not hard as in the adult, and is adapted to receive its mother's milk.

Parental Responsibility

Birds, even more so than mammals, show a high sense of responsibility in bringing up a family. Before the eggs are laid, the parents get busy building a nest for their reception and incubation. The latter function is usually the prerogative of the female, but in a few cases this duty may be shared by both cock and hen or even entirely undertaken by a broody male. Thus, in the case of the emu and the kiwi, the male alone sits upon the eggs and takes care of the brood. The polygamous ostrich

takes his share in the duties of incubation with numerous wives.

The male penguin is likewise a devoted father and co-operates with his consort in raising the family. Birds when they hatch may be naked and helpless, or covered with feathers and strong in the leg. The food that they are provided with varies. Many are fed on worms and caterpillars. Some are given food pre-digested by the parents. In the case of the pigeons, the food with which the squabs are supplied takes the form of a fluid, pigeon's milk, regurgitated from the lining of the crop.

Ground Nests

The nature and shape of the nest depends not only on the building locality but on the length of time that the chicks will remain in it. Thus in the ostrich-like birds, the eggs are deposited in rough depressions in the ground. These birds are hatched in a very forward condition. They must be quick on the leg soon after leaving the egg and in a position to make a hurried move on the exposed plains, where they first see the light of day, in order to escape from predacious enemies. Among other birds that lay in depressions on the ground, lined with perhaps a little grass or sheltered by low vegetation, are bustards, penguins, skuas, gannets, grouse, partridges, nightjars and stone-curlews.

Nests which take the form of rough structures are built by pelicans and herons. Birds that lay in holes in trees, river-banks or rocks include parrots, trogons, hornbills, toucans, owls, jackdaws and kingfishers. The bowl-shaped nest, composed of grass, twigs, root fibres, moss, etc., and lined with feathers, which in the case of the ducks, geese and swans are not those of other birds, but are plucked from the parental body, is the type most in favour. Certain honey-eaters rely mainly on the hair of animals for their nests, and an Australian species builds with the cast-off clothing of kangaroos and wallabies.

Some seventy-five years ago, the country on which now stands the suburbs of Sydney was well stocked with wallabies and the little honey-eaters relied on the hair of these for building their nests. When civilization crowded the marsupials out of the picture, the birds were forced to seek a substitute building material, and this they found in the next best thing—human hair—which they helped themselves to from the heads of passers by.

The aesthetic bower birds decorate their

MOTHER OPOSSUM CARRYING YOUNG

The opossum lives in Australia and the Americas. Some have pouches in which they carry their young, and others are without them. The common opossum bears two or three litters a year. When they are old enough to leave the pouch the young cling to the mother's back.

OSTRICHES EMERGING FROM THE EGG

Young of birds which lay their eggs in exposed places are hatched out in a very forward condition. Ostrich chicks are fully fledged and able to run about from the start.

nests, formed of grass, twigs and mud, with shells, feathers or flowers which are renewed as soon as they fade. Of the many different species, each has its own conception of the ideal home.

Mound Builders

In the Australian brush turkeys, or mound builders, the males, either singly or in company, erect monumental mounds composed of leaves and debris, in which the hens lay their eggs. The male birds not only build the mounds, which may cover an area of twelve feet square and weigh nearly three tons, but take upon themselves the upbringing of the family. The eggs are incubated by the slow fermentation of the contents of the mound, an incubation which is supervised by the cock bird, who continually tests the heat of the inside of the structure by thrusting in his bare neck, which is thus used as a thermometer. Leaves and twigs are added or removed as required, and so an even temperature is maintained.

Throughout these irksome and arduous labours, the hen sits back admiring her consort's efforts. After about forty days the eggs hatch. On suspecting the hatching to be imminent, the dutiful father removes much of the litter and the chicks struggle to the surface. The latter are independent from the first. Not only can they scratch for a living as soon as they reach the surface of the mound and first see daylight, but are capable of flying a few hours after hatching.

The smaller kinds of penguins incubate one or two eggs in a rough nest on the ground, upon which both parents sit and share the responsibility involved. In the case of the large king and emperor penguins, the single egg is incubated whilst the cock or the hen stands in an upright position, the egg being held in a fold of skin between the abdomen and the legs which closes over it from above like a roof. This not only keeps the egg stable, but the enormous layer of fat which invests the entire bird like a blanket also supplies the heat generated by this strange incubator. Both parents take turns at incubation, a responsibility lasting from a few hours to several days, according to the inclination of the nurse.

Fatigue or hunger dictating a period of off duty, the bird in charge summons its partner by a trumpet-like call. The relieving bird stands shoulder to shoulder with the party on duty, who by a skilful movement of the ankles slides the egg from its instep on to that of the new nurse. On hatching,

BRUSH TURKEY AND NEST

The nest of the Australian brush turkey is composed mainly of leaf mould and is usually in the shade of trees so that the temperature for incubation is derived from the decay of moist vegetable material.

the fledgling is clad from back to ankles in a thick, shaggy suit suggesting an Eskimo's attire. This slowly falls away from the ankles upwards, so that the bird wears successively a great coat, a breast jacket and finally a tippet. By the time this last garment is shed, the bird has attained to full stature.

"Safety first" is the motto of the hornbill, who having wooed and won his mate conducts her to a tree, and having seen her scramble safely through a hole in the trunk plasters up the hole with mud, leaving a mere key-hole for air and the introduction of food. There the hen may remain for two or three months. By this seemingly tyrannical behaviour, the male safeguards the family from snakes and other foes during his absence on foraging expeditions.

Reptiles which may come into the world by being hatched from eggs or being born alive, show as a rule little solicitude for their offspring. The eggs of crocodiles and pythons are, however, the subject of parental protection. Thus, crocodiles deposit their hard-shelled eggs in nests composed of vegetable matter on the edge of the water, where they are carefully watched over by the parents.

Most snakes lay their eggs in decomposing matter on the ground, where they are hatched by the heat of the sun. The python, however, the largest of the world's snakes, displays a very real anxiety for its eggs. In this reptile, the eggs, up to one hundred in number, are protected by the mother, who coils herself round them and subjects the ova to incubation. During this nursing period, which sometimes extends over four months, the temperature of the female rises several degrees above the normal.

As has been stressed already, in fishes the nature and number of eggs laid are indicated by the protection that is given them. In sharks and rays, the eggs are often enclosed in horny envelopes formed by a gland peculiar to these fishes. The corners of the envelopes are usually drawn out into long tendrils, which become coiled on to pieces of seaweed or stones. The eggs are very few in number, only one or two being deposited at a time. The period of development may extend for over a year, the fish escaping eventually through a slit in the envelope.

Some sharks are viviparous, being born

in the perfect form except for carrying a yolk sac from which they continue to derive nourishment for several weeks after being born. In no branch of the animal kingdom has parental care reached such extraordinary heights as among the fishes and amphibians.

Many fish, both fresh-water and marine, build nests for the reception of the eggs and these may vary from simple hollows scooped out in the river- or sea-bed to the most elaborate structures designed to form an impregnable fortress. The fish that excavate such simple depressions include the salmon, the darters, the fresh-water sun-fishes and many cichlid perches. In the salmon and the darters, the labours of scooping out a trough in the gravelly bottom of the river devolves upon the female. In the fresh-water sun-fishes, the work is carried out by the males, and in the cichlids by both prospective parents.

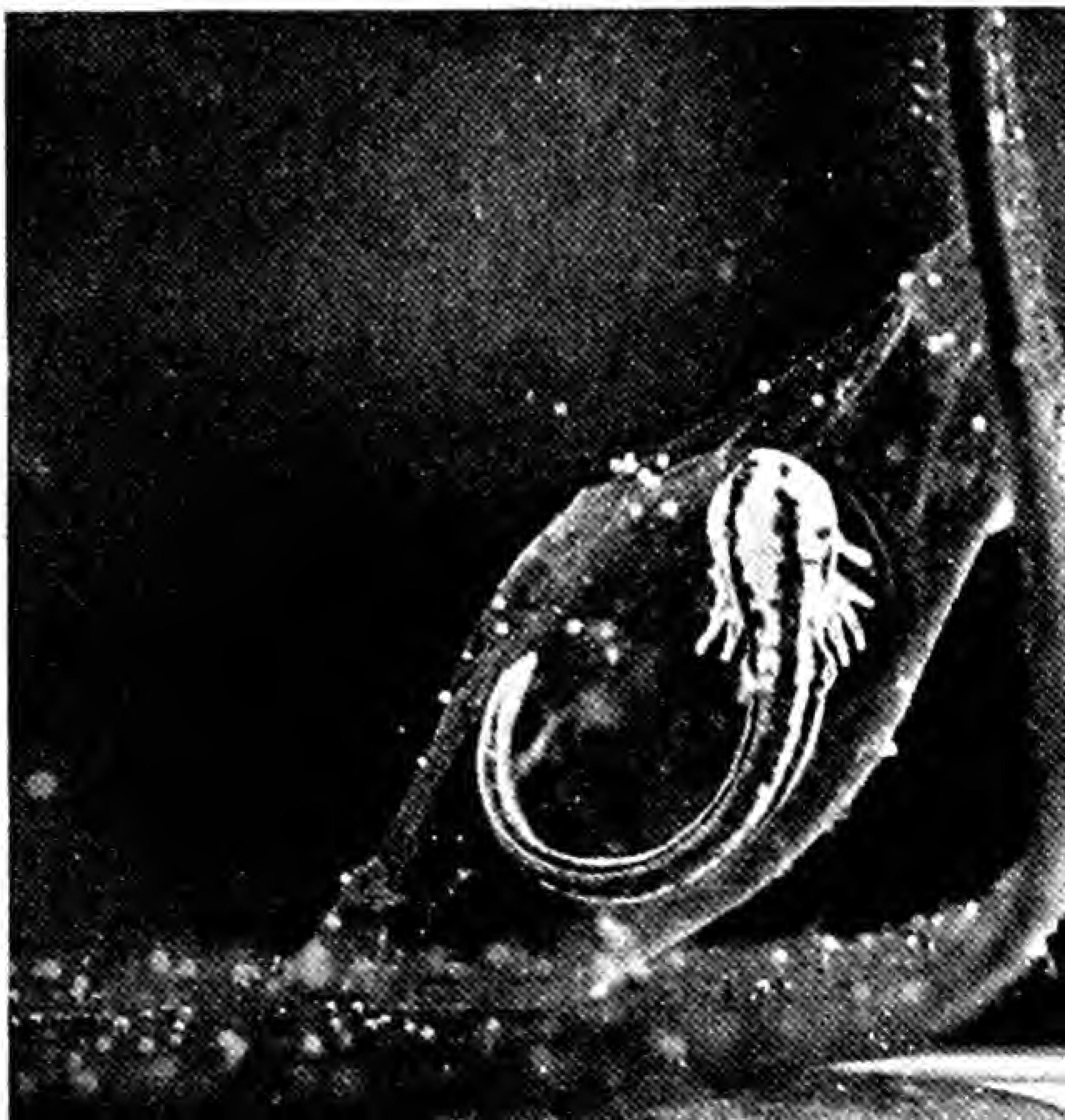
The cichlids, which inhabit tropical Africa and South America, have extensile mouths which are employed in hollowing out saucer-shaped hollows in the sand or shingle. The fish take up large mouthfuls of silt, dumping it at a short distance, until a suitable depression is formed. This labour occupies several days, and the waste rubble of one pair of workers may find its way into the territory of another pair, causing much neighbourly friction. When finally the eggs are laid and hatched, the young fry are a constant source of anxiety. Baby fish that stray too far from the nest are hastily retrieved by the process of engulfing them in the parental mouth and bearing them back to the nursery. Other fresh-water fishes construct nests by clearing passes among reeds and other aquatic plants. The male of the North American bow-fin, an elongate fish measuring up to two feet in length, builds a large nest by clearing a circular space, two or three feet in diameter, among rushes. He mounts guard over the nest and protects the eggs from predacious enemies, among which, by no means the least dangerous, is the cannibalistic mother.

The nest of the African fish, *Heterotis*, built in shallow water, may measure four feet in diameter and the three-inch-thick walls are constructed by both parents of the stems of plants removed from the centre.

The male African lung-fish excavates a fairly deep hole in the mud of a reedy swamp and not only keeps a watch over the eggs but aerates the surrounding water by lashing it with his tail and thus supplies the ova with the necessary amount of oxygen.

The three-spined stickleback is the builder of an elaborate barrel-shaped nest formed of weeds, roots and twigs bound together, its construction being undertaken entirely by the male.

The late J. R. Norman has quoted some notes made by Lord on the building of the



PROTECTION DURING DEVELOPMENT

Newts lay their eggs in groups carefully attached to the leaves of underwater plants. A young newt is seen developing within its protective egg-case of jelly.

nest and the precautions taken by the father fish to ensure the safety of the eggs. Lord observes that "during the operation of building, the male tests the nest's durability and strength: he rubs himself against it and scrapes the slimy mucus from his sides, to mix with and act as mortar for his vegetable bricks. He thrusts his nose into the sand at the bottom and engulfing a mouthful scatters it over the foundation: this is repeated until enough sand has been thrown on to weigh the slender fabric down and to give it substance and stability. He then twists and turns to test the firm adherence of all the materials. The nest or nursery, when completed, is a hollow, somewhat rounded, barrel-shaped structure. The inside is made as smooth as possible by a kind of plastering system; the little architect continually goes in, then, turning round and round, works the mucus from his body on to the inner sides of the nest, where it hardens like a tough varnish. Having finished the home, which may take several days to complete, he goes in search of a mate and after an elaborate process of courtship conducts her to the nest. While she is in the nest, she deposits two or three eggs. The female then swims away and the male seeks out other brides. When sufficient eggs have been deposited, the male mounts guard over the entrance, defending his charge with vigour against all comers for nearly a month, furiously attacking any other stickleback that attempts to approach the nest. From time to time, he repairs any damage to the walls. Every now and then he shakes up the material and drags out the eggs, which after replacing he tucks up again with his snout."

The nest may be said to be water-conditioned, since the doorways allow for a constant current of fresh cool water to pass through. Even after the young hatch, the father's duties are not completed, for he converts the nest into a cradle by pulling down its upper portion. The fry for some weeks after leaving the egg are prevented from exploring their surroundings and any truants are immediately pursued, seized in the parental mouth and returned to their cradle.

The rainbow-coloured paradise fish of China, and the fighting fish of Siam, make nests formed of bubbles, which the males blow on the surface of the water and in which they place the eggs laid by their partners. The bubbles are coated with a sticky saliva which hardens and causes the structure to set.

Mussel's Protegé

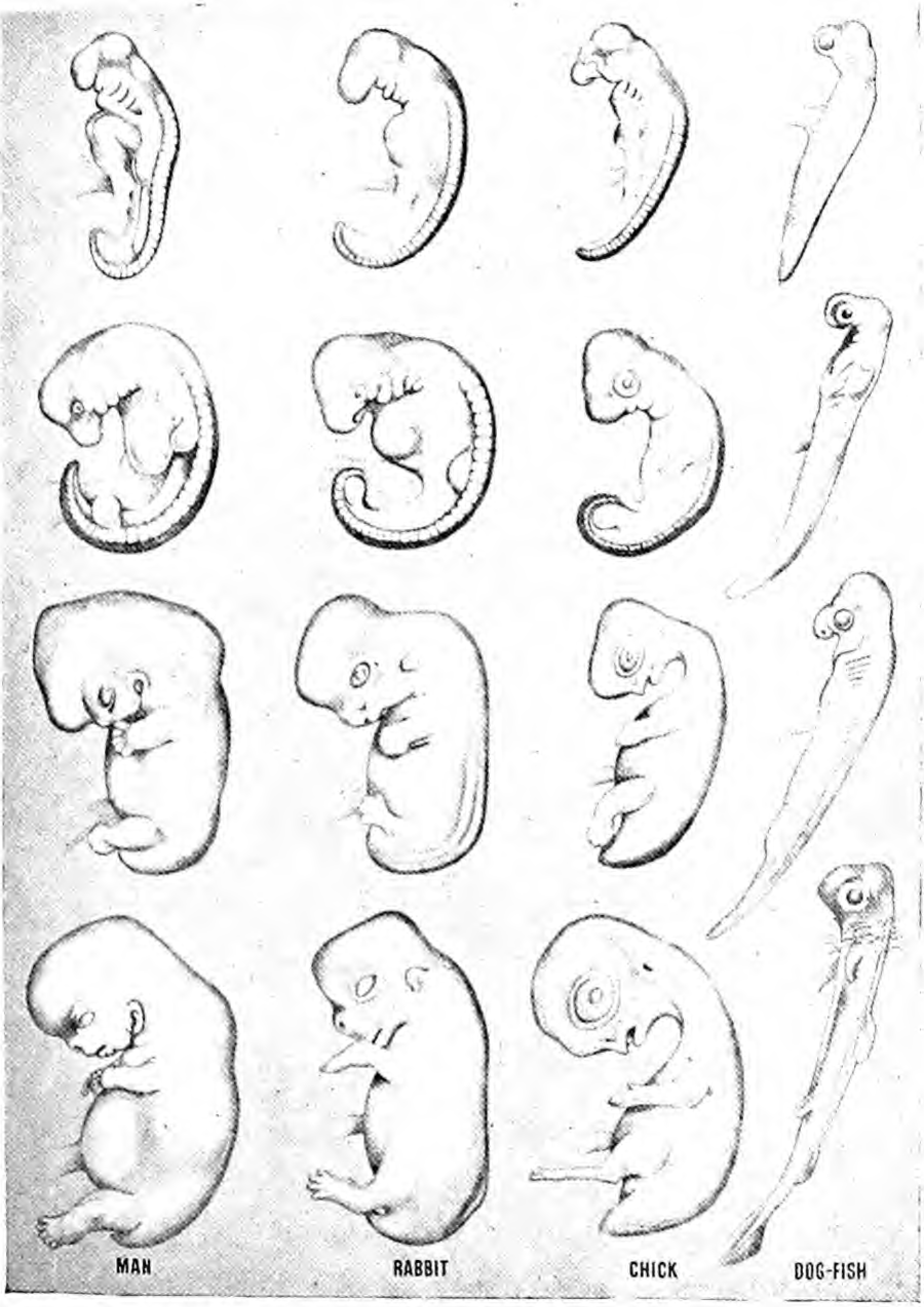
The eggs of a small Central European carp are laid in the mantle cavity of a pond mussel where they hatch, beyond the reach of foes, the respiratory current of water, inhaled by the mollusc, serving to aerate the ova. The mussel repays itself for its hospitality by discharging its own embryos into the water, where they spend their infancy beneath the scales of the fish. Not until they are perfectly formed mussels do they leave their host.

The female butterfish of British waters rolls her eggs into a compact ball and protects them by coiling herself about them. Still more remarkable is the manner in which the male sea-horse carries the eggs in a kangaroo-like abdominal pouch formed of two flaps of skin upon the undersurface into which they are deposited by the female. The baby fish, when they emerge, hover for a time round their father, anchoring themselves to his caudal appendage by their own long prehensile tails.

In Mother's Mouth

Parental care in fishes reaches its zenith in the case of those which retain the eggs in their mouths until they hatch. In the case of an African perch, the mother shelters about fifty eggs in her mouth for a period of a little over a week. For the first few days after hatching, the little fish keep in close proximity to their mother's head, and in the event of danger the young disappear with lightning-like rapidity into the familiar retreat. In an American catfish, the eggs are retained in the mouth for over two months, during which period the mother abstains from feeding.

The young of certain members of the mackerel family seek protection from enemies by taking shelter under jellyfishes. So long as their presence is undetected, they suffer no harm from their invertebrate



EMBRYOS IN FOUR STAGES OF DEVELOPMENT

Young embryos of related animals look much alike. In this picture the youngest forms are shown at the top, progressively older stages as we proceed down the picture. As they grow older they gradually become less alike.

hosts, whose long stinging tentacles seize and paralyse other small fishes. Dr. Beebe has given an account of the conditions under which the young mackerel associate with the jellyfish. The jellyfish, he states, "probably does not even know of the fishes' presence until one of them ineptly bumps against the hair-trigger of its nettle-batteries and affords it a hearty meal."

A jellyfish, measuring two by four inches, which Dr. Beebe captured, contained no fewer than a dozen healthy little fish, which, as he observes, must have been packed together like sardines in a tin.

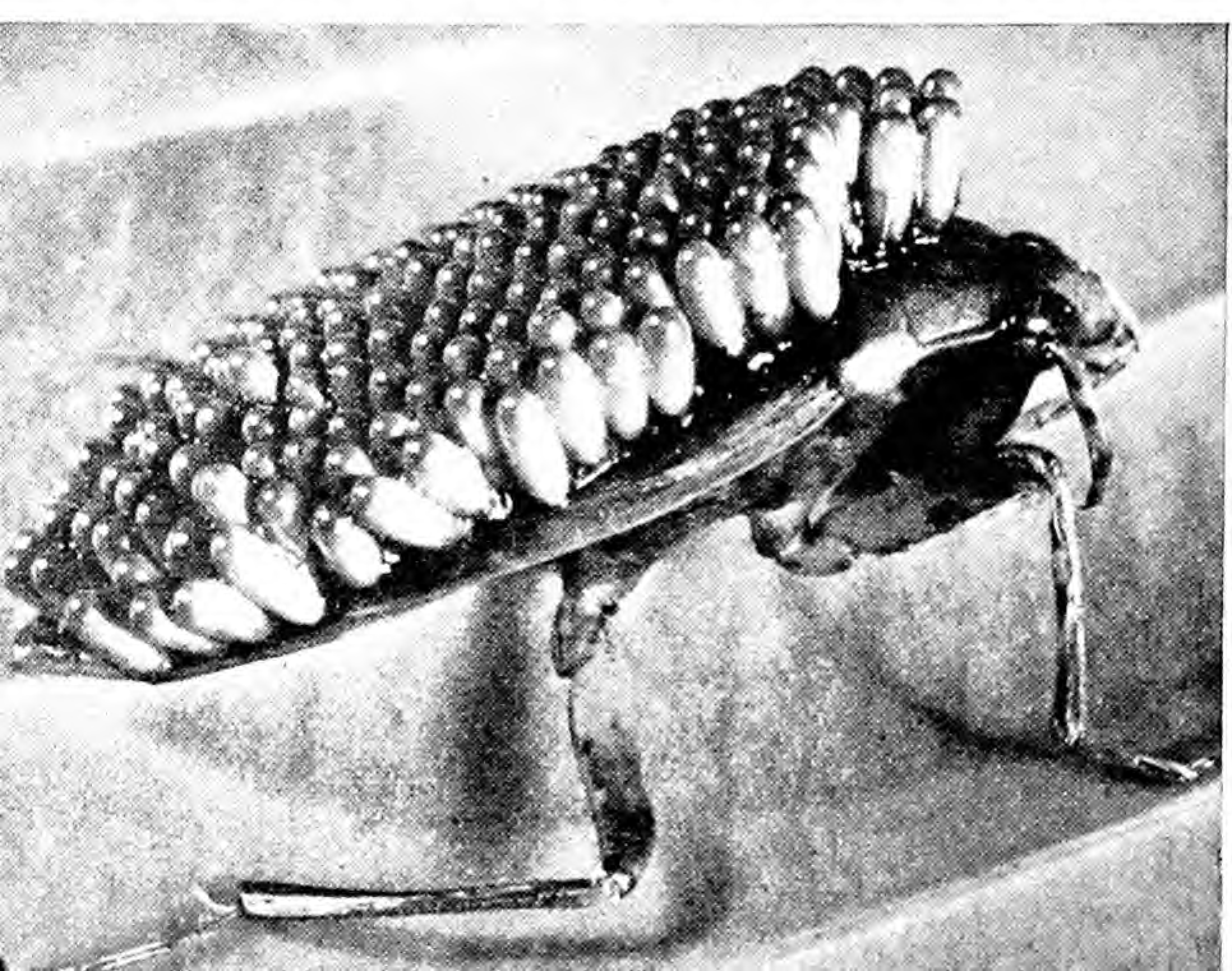
Certain frogs and toads are as adept at nest-building and the careful bringing up of a family as are many birds. Thus, an American tree-frog lays its eggs in several leaves woven together, the nest recalling that of a weaver-bird. The cradle containing the egg-masses overhangs the water, into which the tadpoles fall when in a late stage of development. An Indian frog deposits its eggs in frothy nests, which likewise overhang water into which the tadpoles fall. The frothy nursery is formed by a secretion exuded and beaten up by the mother. An Australian frog likewise builds a bubble nest, but here it floats upon the surface of the pond, and in this raft the eggs develop.

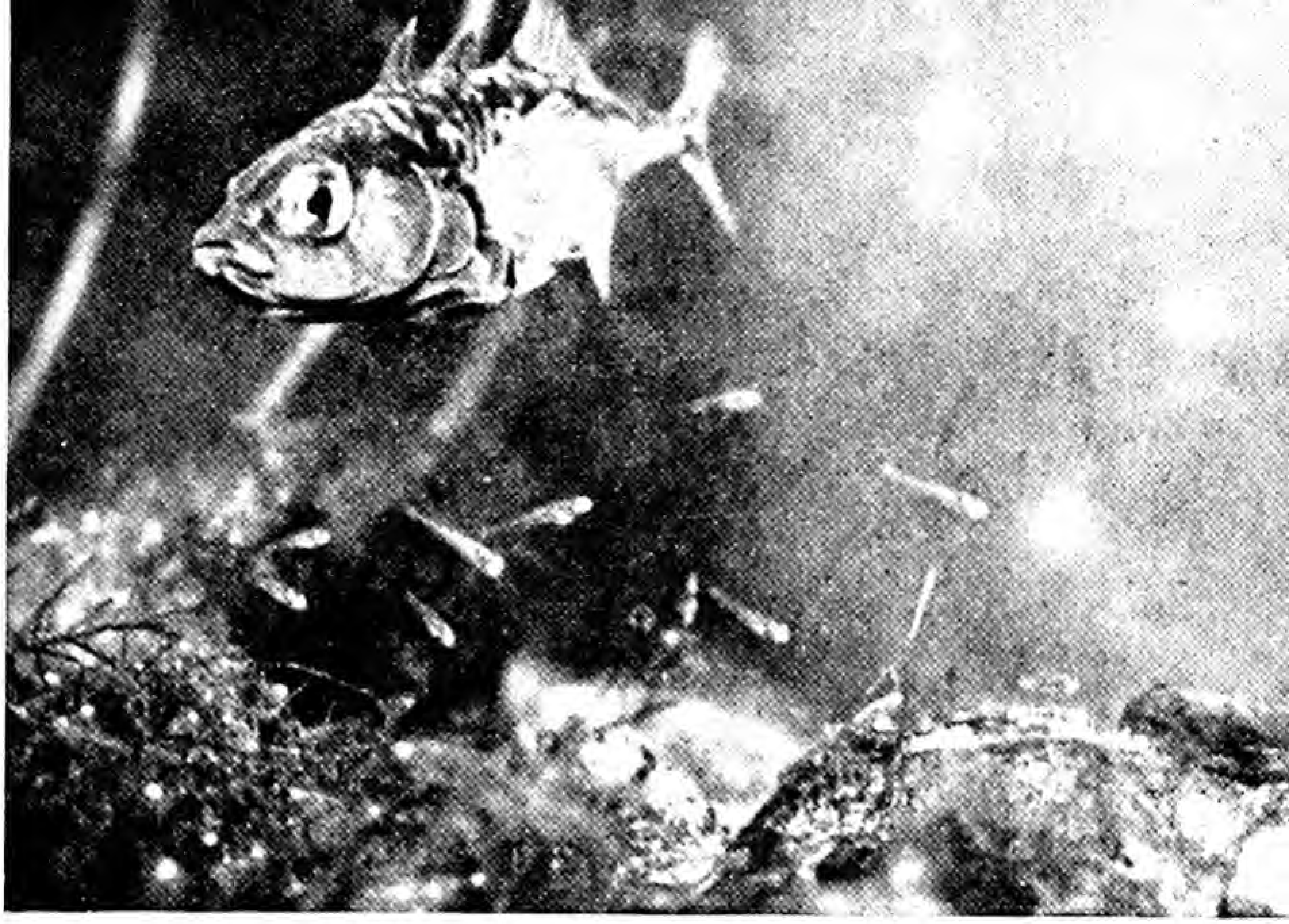
Some frogs build miniature swimming pools formed by enclosing a portion of a pond by surrounding it with mud walls. In this secluded piece of water, the tadpoles live secure from enemies. Their metamorphosis into perfect frogs synchronizes with the rainy season, when the walls of their enclosures become demolished. The walls of the watery nursery are in some species fashioned by the male, in others by the female, the parents using their hands and feet to press the mud into position and smooth the inner sides of the barricade.

Most remarkable is the manner in which the father of a little South American frog carries the eggs, which it swallows, in a seasonal enlargement of its vocal sac. The eggs are placed in the sac as soon as laid,

MALE PARENTAL CARE

A male water-bug carries round the eggs which have been deposited on his back by the female after mating. In this way they are protected from other animals which might eat them.





STICKLEBACK GUARDING FAMILY

The male stickleback is the more active partner in the family life. He builds the nest, cares for the developing eggs and shepherds the young ones until they can fend for themselves.

by the male parent, who pushes them into his mouth with his hands. Nearly the whole of the development takes place in this strange retreat, the tadpoles' tails becoming absorbed before the infant frogs are allowed out into the world.

Midwife Toad

Another amphibian nursing father is the European midwife toad. Pairing takes place on land, when some fifty eggs are laid in a rosary-like string. Whilst they are being expelled, the male thrusts his legs through the egg-mass and the strings become entwined round his legs. Encumbered with his burden, he retires to some underground retreat, from which he ventures forth at night to take a hip-bath, with the object of moistening the eggs. At the end of four or five weeks, the larvae are ready to hatch and the father takes to the water, where the family is released in the form of large tadpoles in an advanced stage of development.

A Brazilian frog spawns in shallow pools or puddles, which rapidly evaporate. When these dry up, the tadpoles are transported to some other shallow pool, clinging to their father's back by their sucker-lips. In the course of their development, the larvae may visit several pools and enjoy a protracted tour. A frog found in the Seychelles likewise carries its tadpoles on its back. In the case of this creature, the larvae cling to their parent by means of their adhesive bellies: they are not released in water, but undergo their entire metamorphosis attached to their mother.

A very queer nursery is that of the pipa or Surinam toad. The eggs, up to about one hundred in number, are pressed by the male from the long extensible oviduct into the back of the female, where they sink into the skin, which during the breeding season becomes spongy and yielding. The cavities so formed become covered after a few days with a horny lid—a drumhead of skin—each egg lying within a separate cell. About three months later, the young lift up the lids and emerge as perfectly formed little toads, having spent their entire tadpolehood in holes on the maternal back.

Parental care is practised even among

FOX CUBS AT PLAY

Vixens produce only one litter a year, usually of four or five cubs, which are born in the spring. The cubs are blind for about ten days after birth, but by the autumn they are able to shift for themselves : they become adult when about a year old. Their mother does not pay much attention to them, but leaves food at a distance for them to pick up for themselves.

the invertebrates. Many crustaceans carry their eggs about with them attached to the under-surface of the tail, whilst some bristle-worms carry them stuck to their bodies.

Nursing fathers are represented among the lowly. Thus, the males of certain sea-spiders burden themselves with egg-bundles abandoned by the females and are provided with a special pair of appendages with which to carry them. A British star-fish, and the mollusc known as the China-man's hat limpet, sit over their eggs until the young hatch out. The female octopus is a devoted mother, for, throughout the month-long incubatory period of her eggs she sits by them, encircling them with her tentacles, whilst her syphon pipe, turning first to one side and then the other, passes a constant stream of fresh water over them.

Growth and Age

Plants grow throughout their lives, their growth being restricted by merely seasonal conditions. Some of the lower animals likewise increase in size from the day they are brought into the world to the day they die, there being no definite limit to their growth. In many creatures, the rate of growth depends upon the individual food supply and environment. Age in fish, for instance, is not by any means compatible with size, a pike weighing thirty pounds being not necessarily older than one less than half that weight.

In land animals, the weight of the body is correlated with the carrying capacity of the legs. The larger and heavier the body becomes, the stronger must be its supporting limbs, and for this reason Gulliver's giants were physical impossibilities. A scale enlargement of a man forty feet high would collapse, since the legs would snap under the body bulk. Terrestrial animals can never hope to attain the dimensions of those inhabiting aquatic conditions, and consequently the champion heavyweights of the various branches of the animal kingdom, with the exception of the birds, are all aquatic. They are: mammals—the whale, one hundred and fifty tons; fish—the whale-shark, four tons; reptiles—the crocodile, one and a half tons; molluscs—the giant squid, three tons; crustaceans—the giant Japanese spider crab, fifty pounds.

No terrestrial creature has exceeded the elephant in size (five tons), if we except the vast dinosaurs, which, like other monsters of the past, came to an untimely end. The

gorilla, the largest of the man-like apes, may attain a weight of over forty stone. A specimen which lived from 1928 to 1935 in the Berlin Zoo weighed, on arrival, when about two years old, thirty pounds. Its weight increased year by year until death, when it weighed no less than five hundred and eighty-four pounds. Weight has fortunately dictated the limitations of a creature as regards the mastery of the air, the heaviest flying birds—swans and vultures—weighing well under twenty pounds.

No insects attain to any great weight, being very light in proportion to their bulk. Eighty thousand fleas, for example, go to the ounce and the relatively heavy queen bee weighs less than a gram.

The disadvantages suffered by these light-weights are many. Thus, most insects are unable to drink in the accepted manner and obtain their moisture by sipping from damp surfaces. Water in bulk is a barrier to them since, should an insect become wet whilst attempting to drink, it would be handicapped by having to lift many times its own weight. As Professor J. B. S. Haldane has pointed out, "an insect going for a drink is in as great a danger as a man leaning out over a precipice in search of food."

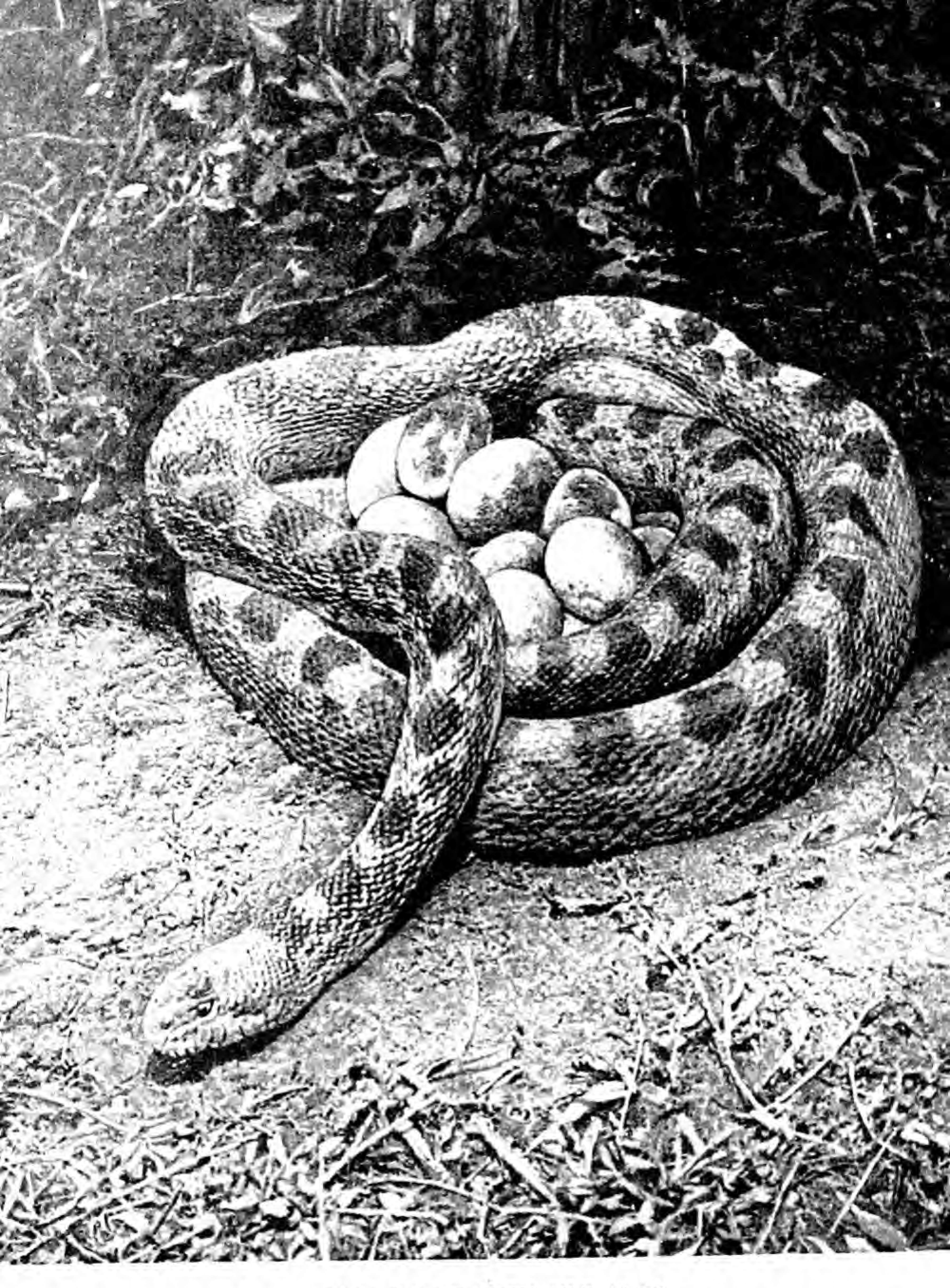
Although amongst many animals there is a relation between longevity and size, such relationship does not always apply. Thus, man may live to be over a century, whilst the gorilla, which attains a much larger size, seldom survives a third of that period. The only creatures known definitely to outlive man are the giant tortoises of the islands of Aldabra, near Madagascar, and Galapagos, off the cost of Ecuador, and possibly the eagles and vultures. Some of the largest tortoises have histories dating back over two hundred years. Longevity records have been collected by various authorities, whose findings, in the case of the mammals, are as follows :—

Man, one hundred and ten years; elephant, eighty years; rhinoceros, forty-five years; hippopotamus and horse forty years; bear, ape and giraffe, thirty-five years.

Large animals tend to mature more

NATURE MAKES PROVISION

A young mammal is dependent on its mother's milk until it can fend for itself. Milk contains most of the food factors which an animal needs. Here we see a sow feeding her young. Domesticated pigs produce an average of eight to ten pigs in a litter.



PINE SNAKE WITH HER EGGS

The majority of snakes lay eggs, although some such as the adder are viviparous, bearing their young alive. Reptiles as a general rule show little solicitude for their young, and most snakes leave their eggs to be hatched out by the sun. A few, however, coil themselves around the eggs and keep them warm in much the same way as a bird incubates its eggs.

slowly than small ones. An elephant, for example, is incapable of breeding before it is about twenty years old. But, again, there are exceptions, of which the whale is probably the most outstanding one. The span of life of a whale is believed to be comparatively lengthy, yet the largest species, measuring over one hundred feet in length, are capable of reproducing their kind when under three years of age. At birth, the baby whale is more than one quarter the size of its mother.

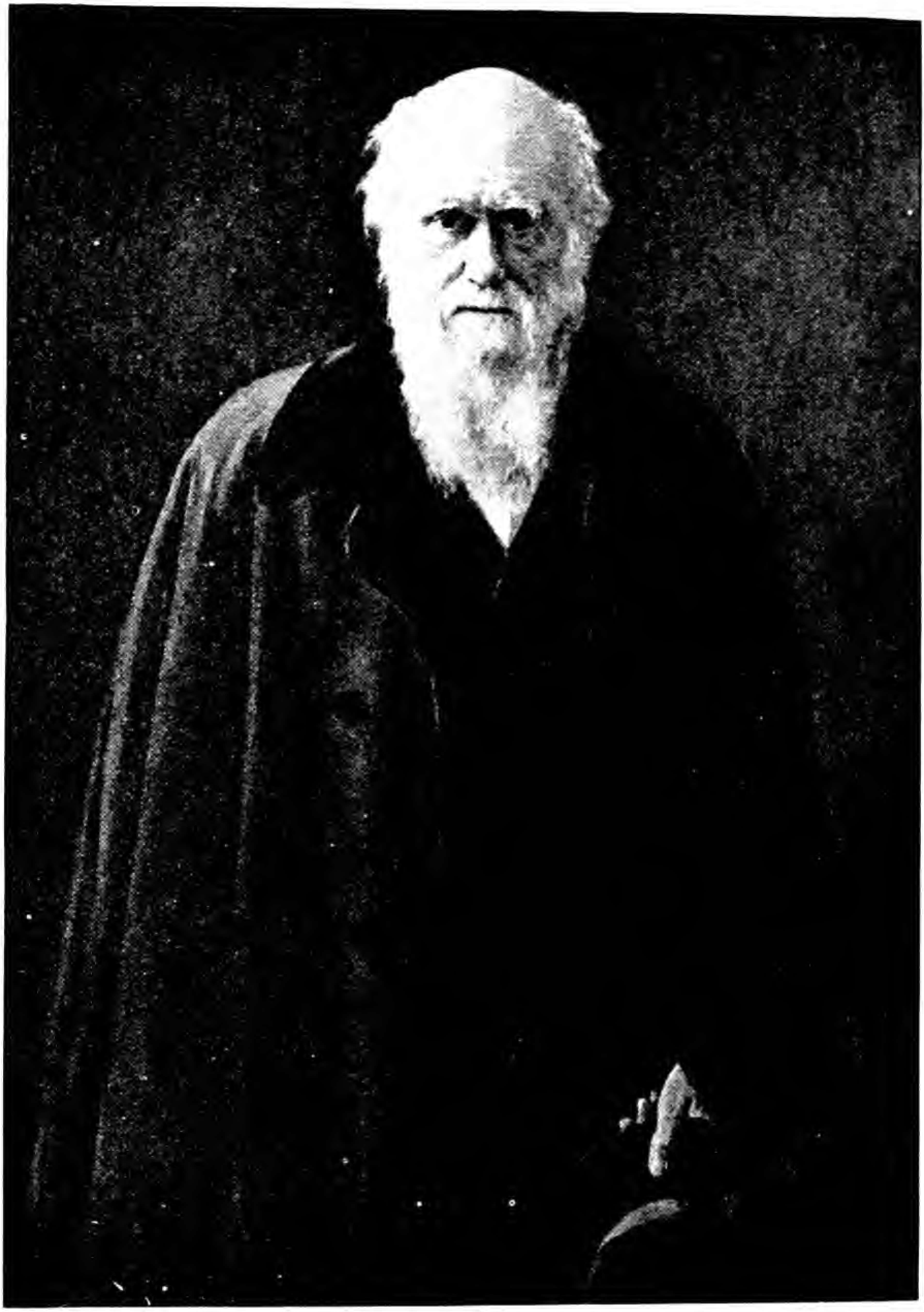
Many birds attain considerable ages. Some of the largest live longer than any mammals, whilst many quite small birds outlive such large beasts as apes, lions, tigers, bears, etc. The record is held by the Egyptian vulture, which has been known to live for one hundred and eighteen years. A canary may live to twenty years and the nightingale and skylark for a few years longer.

The fact that the cassowary does not live nearly as long as a parrot, raven or gull, and that its potential longevity is on a par with that of the nightingale and skylark, shows that in birds there is certainly no relation between size and age.

Test Yourself

1. Can you explain why higher organisms usually are less prolific than lower organisms?
2. Why would you describe the axolotl as the Peter Pan of the animal world?
3. How does the shelled egg mark an important forward step in evolution?
4. What are the advantages of parental care and what relationship has child welfare to the size of family?
5. Can you mention any instances in which the male assumes the duties of looking after the young?
6. Can you suggest why parental care among some fish and many amphibians reaches such a high standard?
7. Explain why the giants in Gulliver's Travels were a physical impossibility.
8. Why should large animals tend to mature more slowly than small ones?

Answers will be found at the end of the book.



CHARLES ROBERT DARWIN

Famous exponent of evolution. His book " On the Origin of Species," published in November 1859, aroused a storm of controversy and was violently attacked on religious grounds. Scientists, however, accepted most of Darwin's conceptions, although some of his beliefs have been challenged since his day.

CHAPTER XIV

DARWINISM TODAY

CHARLES DARWIN's great contributions to biology are twofold. He was the first to make evolution (the doctrine of descent with modification) seem really probable; and he produced a theory of its mechanism. These two contributions are often confused. Indeed it is not always easy to keep them clearly separated when reading the *Origin of Species*. And it is most important to remember that they are not mutually independent. Few would now deny that evolution has taken place; but very many people have criticized his theory of its mechanism, so much so that others have jumped to the conclusion that "Darwinism is dead." It is not dead; but it has changed in growing up.

The idea of evolution is now generally accepted; the opposite view, that of the fixity of species, is not maintained by any scientist. We are all familiar with the notion that all mammals are the more or less specialized descendants of a much less specialized ancestral stock. And, with the great progress that has been made in palæontology, it is possible to show a fairly complete chain of forms linking the primitive mammals with one group of extinct reptiles. Similarly, the birds can be linked with another quite different group of reptiles, to which the modern snakes and lizards are related. But there is some difficulty in linking the Vertebrates as a whole to any other great group of animals, and some invertebrates are almost completely isolated. And it was not possible until recently to show transitional forms between species, such as the doctrine of continuous descent requires.

Darwin's Argument

Briefly, Darwin's argument was this. There is in the world only a certain amount of food for any sort of animal. But animals breed and produce many more, all requiring food. They will come into competition with each other for the available food, whether plant or animal, and they will be preyed upon by other animals. But the individuals of any species of animal vary just as individual men do. Then if one particular animal has some advantage because of its particular set of variations it will be more successful than others of its kind, and in the long run will produce more offspring, the others perhaps being killed outright by starvation or by their enemies. In this way, a generalized stock might split up into several lines, each one specialized in a particular way and so more efficient for its particular mode of life.

There are three points in this argument, firstly that there is competition—a struggle for existence, secondly that animals vary, and thirdly, as a result of these two, that natural selection will take place. Darwin considered that as a result, over very long periods of time, sufficient change could be produced to account for the amazing diversity of living creatures. And the intensity of competition, the enormous pressure of natural selection, would explain the marvellous adaptations of so many animals to particular modes of life.

Darwin's ideas on variation and heredity were those of his time. He collected an immense amount of information on variation in both wild and domesticated animals, and concluded that all animals vary in a more or less continuous way. Tallness in men is an example of a continuous character. Very tall and very short men are the extremes of a continuous series, and there is little or no possibility of sorting men out into definite and separate classes by their height. But in man and many other animals it occasionally happens that an albino individual is found with no pigment in its skin and eyes. Therefore it is possible to place any man into one of two classes with respect to skin pigment—either he has some, or none. Such large differences, which appear suddenly, are known as sports or mutations, and Darwin considered that even when advantageous they would be

swamped by crossing with normal individuals, so that the continuous variations were the important ones for evolution. Further, new breeds of domesticated animals were obtained through deliberate selection by the breeders, by gradual improvement to suit their ideas.

It is obviously necessary for any particular character to be inheritable if its advantageous effect is to be continued in the next generation and it is to become a general character of that particular stock. In Darwin's day the methods of inheritance had not been studied successfully to any great extent, and it was not until Mendel's work had been rediscovered and amplified that there was any theory of heredity based on experiment. The science of genetics is the subject of another chapter in this volume, and there is no need for repetition here, but its implications for evolution are most important and will be discussed. Later, Darwin produced a theory of heredity, which was not adequate, and since it has never been of great importance it need not be considered.

Explaining Relationships

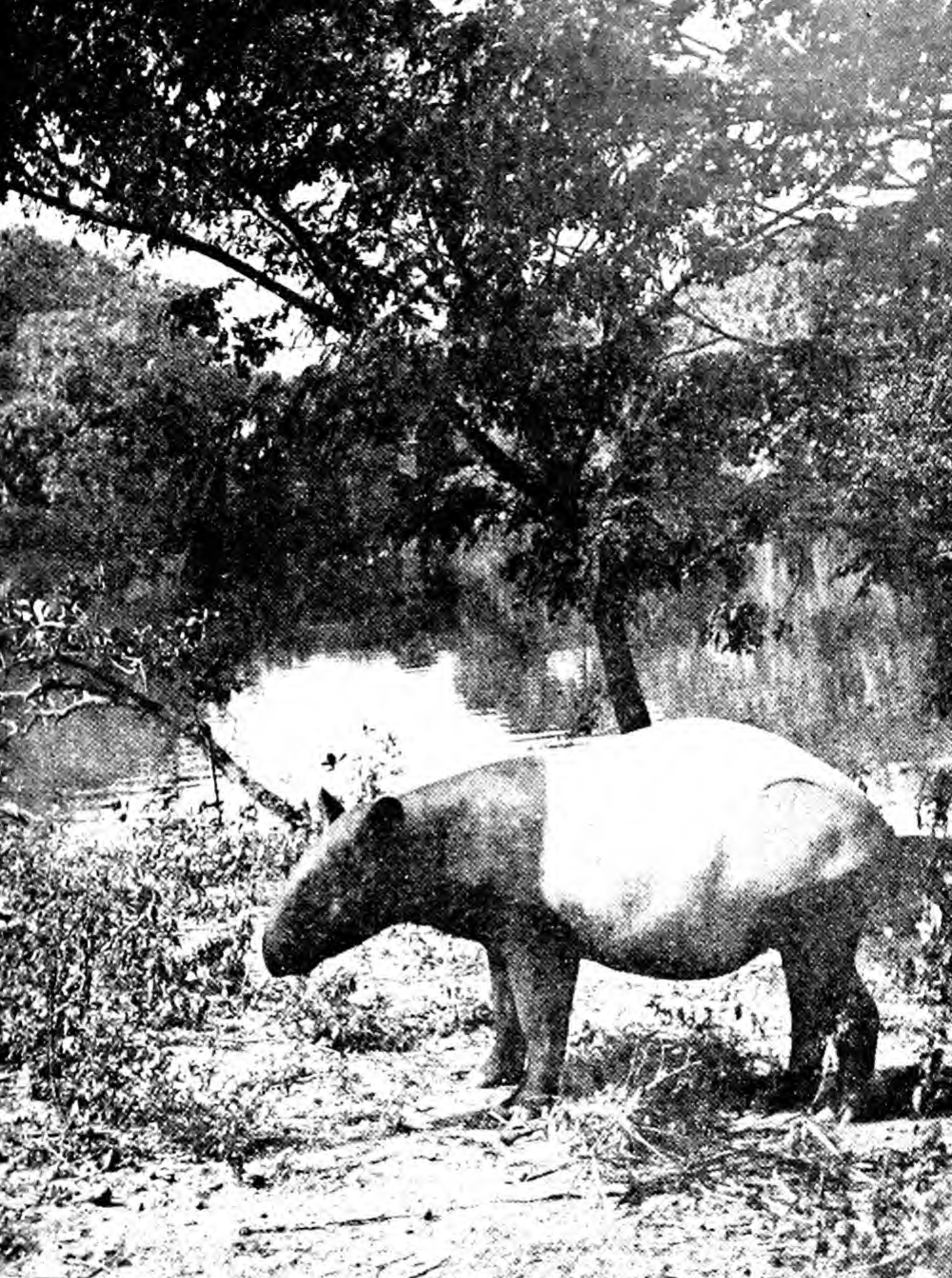
The idea of evolution was immediately and successfully applied in explaining the relationship of all sorts of structures in different organisms. It implies that modification is correlated with some definite advantage, and the biologist should try to find what it is. And by the theory of evolution the possession by various organisms of the same fundamental plan of organization meant that they were all descended from some common ancestor. As a consequence, classificatory systems became for the first time summaries of family trees. With the steady progress made in palæontology, some very complete lines of descent, often with very complex side branches, were described, of which the most famous are those of the horses and of the elephants, though there are others almost as complete. When an animal is exceedingly modified, the discovery of its relationship with others may be very difficult especially when, as is often the case, there are no fossils to help.

Frequently, very important evidence can be obtained from the way in which the animal develops. It is not true to say that in development we recapitulate earlier stages in the history of the race; but it is true that in general two related animals resemble each other more in their anatomy when embryos than when adults. Some remarkable parasites on crabs which are little more than tumours when adult start life as larvæ with very strong resemblances to the larvæ of crabs and lobsters and other crustaceans; they are in fact forms of barnacle but very highly modified, and so are closely related to crabs and lobsters.

Common Ancestors

It is now considered that the primitive stock from which sprang the pigs, the camels, and the highly specialized cattle, antelopes, deer, and giraffes, was closely related to the primitive stock which gave rise eventually to the carnivores. In these, forms like the civets, mongoose, and others seem to have produced the hyenas and the great cats; forms like the weasels, stoats, skunk and badger are near the base of the dog, raccoon and panda, and bear lines; and similar but extinct forms are now represented by the seals, sea-lions, and walrus. But the horse, together with asses and zebras, is the living representative of a very long line, including the ancestors of the rhinoceros and tapirs (and several side branches now extinct), which goes back to a quite different primitive stock from that of the cattle and of the carnivores. Consequently, it appears from the fossil evidence that a cow is rather more closely allied to a lion than it is to a horse. The characters which a horse has in common with a cow and in contrast to other animals such as a bat, an anteater, or a lion, must be explained as adaptations to a particular mode of life. Both horse and cow are large and highly specialized grazing animals, so they have many features in common. But these are due to convergence, not to community of descent. The fundamental plan is different.

To take another example, a whale and a shark have very many similarities simply because they both live in water, and an animal that needs to move rapidly through water must, by the laws of hydrodynamics, approximate to the typical fish shape. But



SPLENDID ISOLATION

Tapirs live in forests in South and Central America and Malaya. In their forest habit they resemble their ancestors, which were also probably ancestors of the horses. By living thus, they avoid competition with other grazing animals which mainly live in the plains.

FLESH-EATING DINOSAURS

Allosaurus fragilis was an American giant reptile of the Cretaceous period. In this picture, based on fossil remains, we see one using its powerful teeth to tear its prey.

a study of their anatomy and mode of reproduction shows, as Aristotle saw clearly over two thousand years ago, that a whale is a mammal, and a shark is a fish.

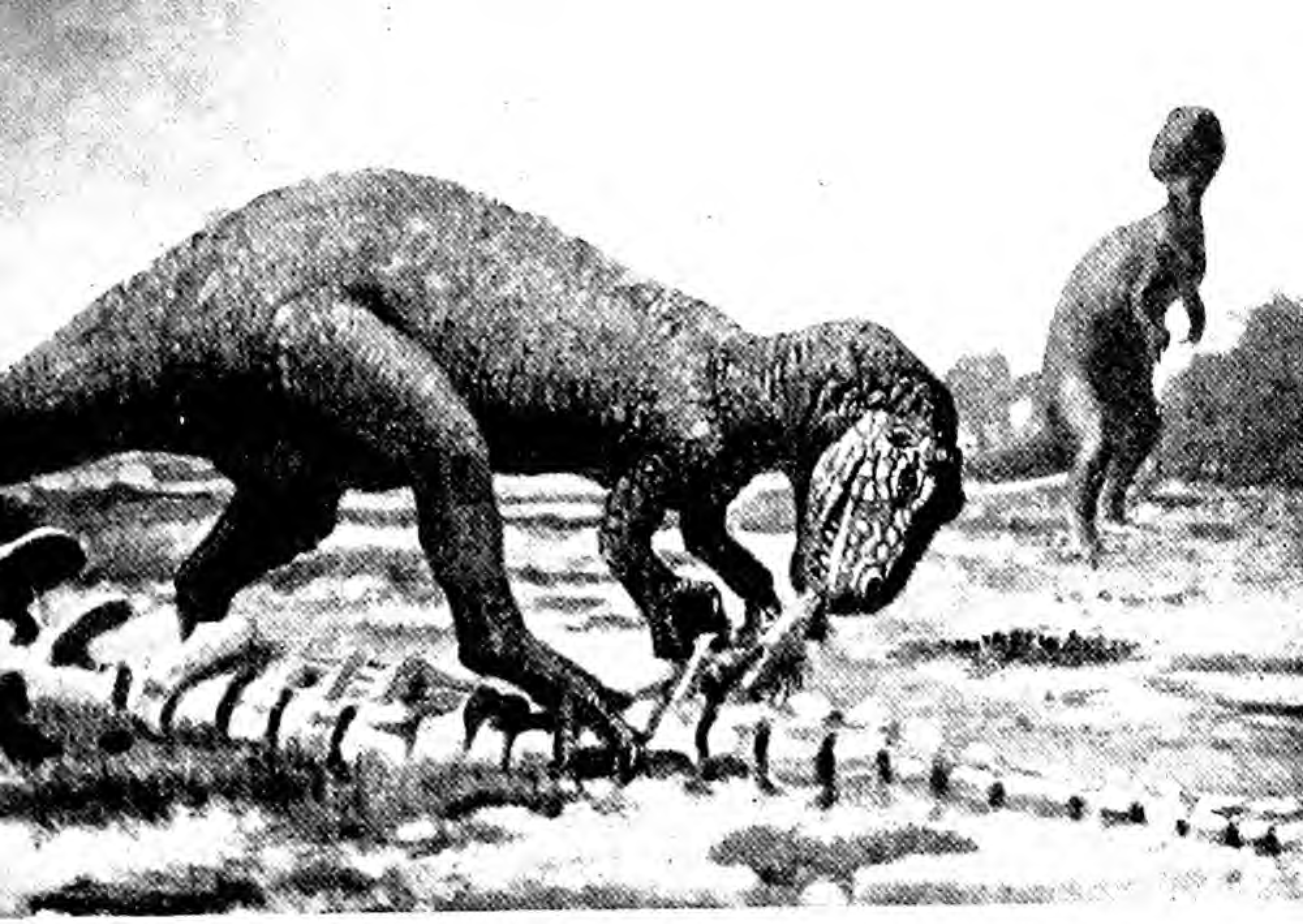
Perhaps one of the most surprising relationships has been discovered since Darwin's time, and links the vertebrates with the starfish, sea-urchin and sea-lily group, the Echinoderms. The larvæ of the most primitive members of the group of Chordates, of which the vertebrates are the major part, bear a distinct resemblance to Echinoderm larvæ and, further, the Chordates and adult Echinoderms both have an internal skeleton, not an external one as have the insects, spiders, and crustaceans.

The vertebrates have been particularly well studied because a great deal of their fossil history is known. It has become apparent that in the course of their evolution there has been on certain occasions an improvement in the body construction. Following upon this, there has been a sort of explosive radiation, a comparatively rapid production of all sorts of species all incorporating the improvement, and all specializing in different ways. Thus, when the first reptiles appeared there was a notable advance in that they were no longer tied to the water. Their eggs need not be laid in a pond for the tadpoles to develop. They could be laid on dry land, and development went on inside the egg, in a sort of private pond, safe from enemies.

Life Invades the Land

Thereupon, a great exploitation of the land began. Herbivores were produced; carnivores developed to feed on them. Some became arboreal, others invaded the water again and competed successfully with the fishes. Almost every way in which food could be got was utilized. There were forms that stole the eggs of the larger animals, and gliding and flying forms, the pterodactyls. When the great reptiles disappeared and the mammals became abundant, there was again an advance, the mammals having more highly organized brains and warm blood (giving them much greater independence of temperature) and much more efficient protection for the young. And very soon there were lines which paralleled to a great extent the reptilian lines. There were forms that flew (the bats), gnawing forms, herbivores of all sizes, carnivores to feed on them, aquatic forms, and so on. A most remarkable parallel can be drawn between the adaptive radiation of the early marsupials in Australia and the later true mammals elsewhere. The wombat parallels the bigger rodents, the Tasmanian cat, the true cats, and the Tasmanian wolf is most amazingly like a true dog or wolf, while some of the smaller forms resemble squirrels and other rodents. There was also a marsupial lion, now extinct, which paralleled the true lions. It is as though there is a definite number of ways of getting a living in the world, and as soon as an advance is made, the new forms begin to produce lines, specialized for each particular way, that in time drive out the older types.

In studying a particular animal, then, its general plan is investigated, and this allows



it to be placed in one of the large groups. The differences between it and other members must then be examined and the reason for them discovered.

On the Darwinian theory all such differences should be adaptive in some way. For example, the hippopotamus, by the structure of its feet and skull, is built on much the same plan as the pigs and peccaries, but it is well adapted for an aquatic life. The giraffe is an enormously tall deer, adapted for browsing on trees. The okapi, which was discovered at the beginning of this century, provides a connecting link, and others are known as fossils.

This raises an important point. The transitional forms between two species related by descent must have been able to exist. But oddly enough, in some cases, there is great difficulty in specifying the characteristics of the link. For example, it is difficult to connect up birds with their reptile ancestors functionally. How can a half-developed wing be of any use, and if it is of no use, how can it have been retained and developed into a complete and satisfactory wing? There are two schools of thought, one maintaining that the immediate ancestor was a bipedal running form which flapped its arms. With the extension of the armscales into feathers, it became airborne by flapping flight. The other school maintains that the immediate ancestor was arboreal, and leaped from branch to branch. With an increase in area due to the development of feathers, it was enabled to glide, much as the flying squirrels and flying lemurs do today, and advanced to flapping flight later.

Distribution of Animals

The idea of evolution was also successfully employed to explain the extremely odd facts of animal distribution. Alfred Russel Wallace, who arrived at ideas of natural selection at the same time as Darwin, though independently, was one of the pioneers here. He remarks at the beginning of his famous book on Island Life, that there is less difference between the animals of England and Japan than there is between those of the islands of Bali and Lombok, only fifteen miles apart, one of which belongs faunistically to the Malayan region, the other to the Australasian. Similarly, there are enormous differences in the fossil and in the living fauna, between North and

LONG-NECKED LEAF EATER

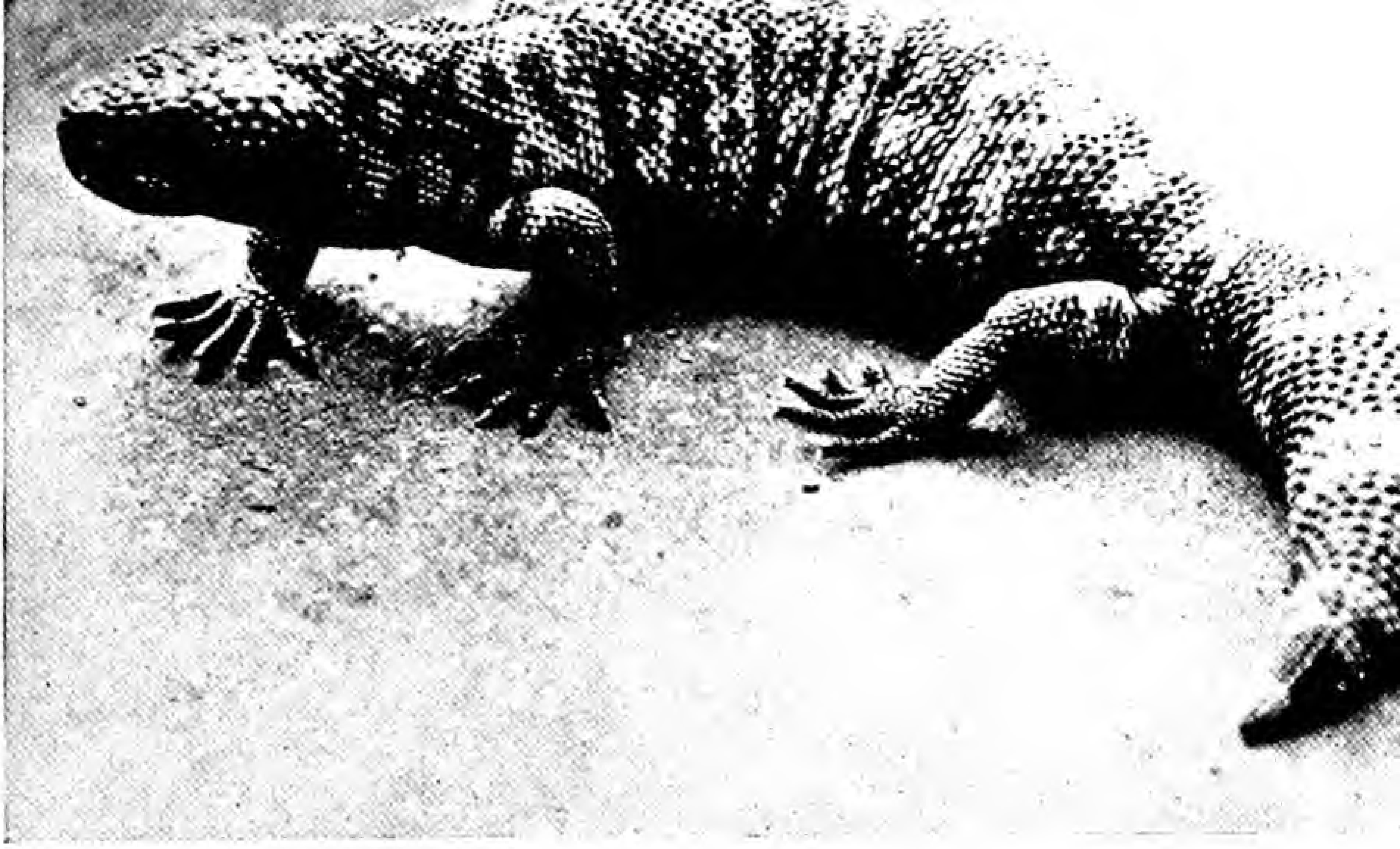
According to Lamarck, the giraffe's neck became elongated through generations of reaching upward for leaves of trees.

South America, far greater than the differences between North America and Europe. The junction of South America to North America is, geologically speaking, quite recent; the separation of North America from Siberia is also recent. Wallace, and Darwin and others, studied the islands of the world and showed that the longer an island had been isolated, and the more isolated it was, the greater was the number of species and varieties peculiar to it. Exceptions were provided by certain islands that had been produced in isolation by volcanic or other origin, and were not well colonized; but these were few.

Britain is an example of a continental island. It has been separated from the mainland of Europe very recently and contains a sample of the European fauna and flora, greatly impoverished by man's activities, but constantly replenished by immigration. Australia, on the other hand, has been separated from the Malayan region for a long time, during which its marsupials have evolved along many different lines, free from invasion by the true mammals. Primitive marsupials, the opossums, found living in North and South America, and fossil in Europe, had a wide distribution, and entered both Australia and South America before they separated off. In South America they gave rise to large carnivores, but later there was a junction with North America and true mammals entered, whereupon the marsupials except the opossums became extinct. The radiation in Australia has already been mentioned.

Animal Coloration

The ideas of the struggle for existence and natural selection provided a means for investigating the coloration of animals. Some animals are very well camouflaged in their natural state, others are remarkably noticeable. The squirrel provides an example of camouflage, and has habits of concealment, but the brilliant black and white of the skunk draws attention to its presence. Many insects are conspicuous, others simulate leaves, thorns, or bark, and some mimic other insects and live among them. It was suggested that concealing coloration helped animals to avoid their enemies.



HELODERM LIZARD

Also known as a Gila monster. The warning coloration is very striking and consists of bright orange or red blotches on a blackish or purplish background. This lizard has poison fangs in the lower jaw and is very vicious when roused.

Brilliant coloration on the other hand was more likely to be a characteristic of animals that are nauseous to the taste, or very tough, or capable of biting or stinging. Such animals would gain by their conspicuousness since it served to warn off possible predators. Yet other species, themselves tasty and harmless, but near in coloration to the tough and nasty, survived by deceiving their predators into believing that they also were nauseous or bellicose.

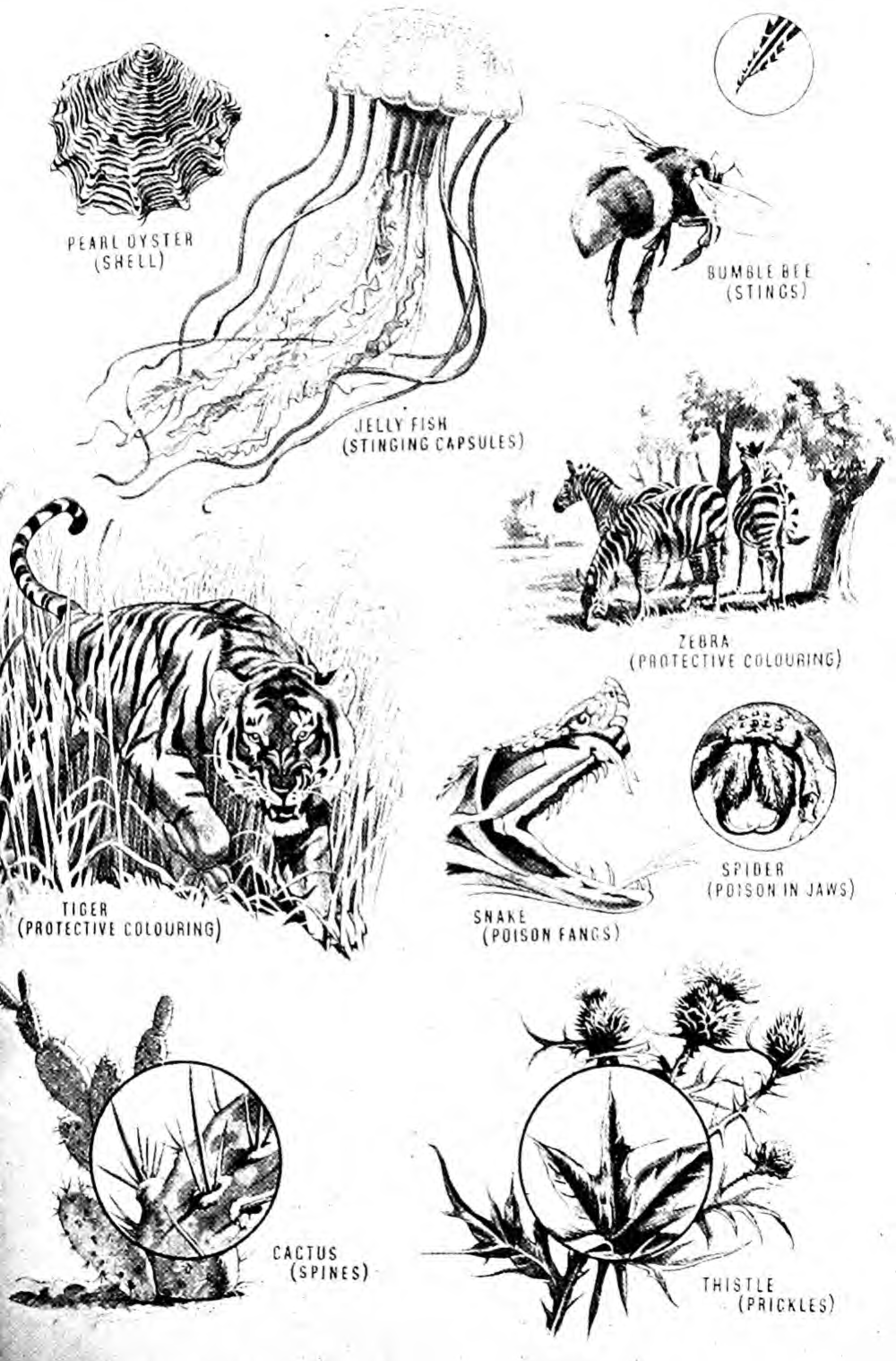
Some interesting series of forms were described in which all the species had much the same warning coloration and mimicked each other. They clubbed together, as it were, to give the same danger signal, so that the predator, having learnt once by experience that a red and black banded insect, for example, was not good to eat would tend to avoid all insects with this coloration. This type of mimicry is called Müllerian in distinction from the other or Batesian.

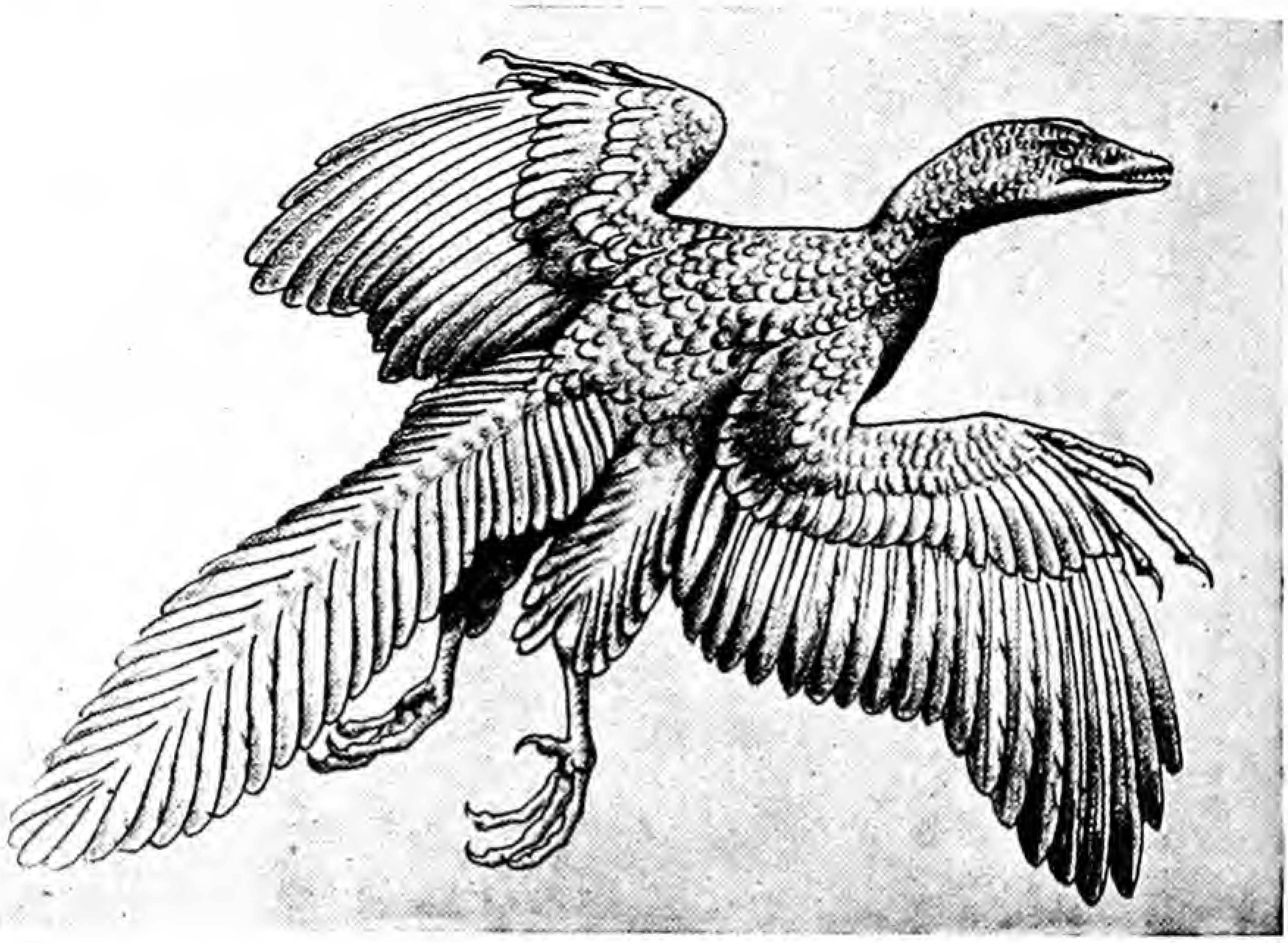
But some colours and organs do not appear to be explicable in this way. The majority of these are ornaments or weapons peculiar to one sex of a species, such as the magnificent plumage of many male birds, and the horns of stags. Darwin explained these by a theory of sexual selection.

He supposed that males would compete for females, and those males with greater strength, better weapons, or more striking adornments would be more successful. Where competition is intense, the ornaments or weapons might be developed to such a degree that they were almost detrimental to the animal except in courting.

But in spite of the many successes of the doctrine of natural selection, there were serious objections to it in principle as well as in detail. For forty years after the publication of the *Origin of Species* there was little criticism, and an immense amount of solid and lasting work was done in comparative anatomy and embryology, the elucidation of true relationships, the development of classifications, and the closer observation of the behaviour of animals in their natural state. The achievements overshadowed the criticisms. But several biologists were very dissatisfied with the idea that evolution proceeds by minute and continuous variations. With the rediscovery of Mendel's work, the science of genetics came into being and the greatest weakness of the Darwinian theory became obvious.

OFFENSIVE *and* DEFENSIVE *mechanisms*


PEARL OYSTER
(SHELL)
JELLY FISH
(STINGING CAPSULES)
BUMBLE BEE
(STINGS)
ZEBRA
(PROTECTIVE COLOURING)
TIGER
(PROTECTIVE COLOURING)
SNAKE
(POISON FANGS)
SPIDER
(POISON IN JAWS)
CACTUS
(SPINES)
THISTLE
(PRICKLES)



CONNECTING LINK

The archaeopteryx, or lizard-bird, forms an interesting link between the reptiles and true birds. It retained many reptilian characteristics including teeth and wing claws. Above is a reconstruction of the bird from the evidence of fossils.

There was a general revival and strengthening of all the criticisms which had been made, and many biologists repudiated Darwinism (but not, of course, the doctrine of evolution) on the grounds that evolution is in fact not by continuous variation, but by definite and discontinuous steps (mutations). Some very influential leaders of public opinion thereupon raised the cry (prematurely) that Darwinism was dead.

Objections to Darwinism

There were four principal objections to Darwinism:

1. The doctrine of the survival of the fittest, it was said, simply means that those that survive do survive. It explains nothing, because natural selection, if it acts, does not select; it is a passive, not an active agency. The outcome of the theory simply is that animals are as they are, and we know that already.

2. It was pointed out that we have no evidence whatever of intermediate forms between species today. A lion is a lion, and a tiger is a tiger. They are very closely related yet they normally never interbreed. There are no intermediates known between rooks and ravens yet they are very closely related too. But if evolution is going on today by modification of species, some intermediates should exist. In short, there is no evidence of the formation of new species or even an incipient sterility between varieties, which might indicate the beginning of species-formation.

3. The rarity of connecting links between the major groups of animals is most striking. The lizard-bird Archaeopteryx forms a beautiful intermediate between reptiles and true birds, but it is a very isolated example. There are very few definitely transitional forms known.

4. The work of various scientists, particularly Mendel, showed that sports or mutations were not swamped as Darwin thought, but were of extreme importance

in the formation of new species, and the mechanisms of heredity that he had suggested were incorrect.

The answers to all these criticisms were found in considering the fourth. The development of genetics brought about a remarkable unification of biology. Whereas before, the sub-sciences of ecology, palæontology, embryology, comparative anatomy, and physiology went on more or less independently of one another, the connexions between them now became apparent and all were essential to the study of evolution.

Darwin believed that characters could vary in a random way, and that they could be acquired, but all were acted on by natural selection. The idea of acquired characters is very important and is constantly being used to support this or that theory. It was first expounded by the great French biologist Lamarck and, in brief, his doctrine was that since use tends to strengthen an organ, if an animal strives to achieve some particular end it will improve the organs involved, as will its offspring. In consequence we can imagine that the neck and legs of a deer-like animal that took to eating leaves of trees, perhaps in times of scarcity, might be gradually elongated until after many generations a giraffe-like creature was produced. This theory assumes that the improvement made in one generation will pass into the hereditary endowment of the next. The Darwinian theory would be that in times of some scarcity the taller deer-like animals would have an advantage over the shorter, their offspring would be rather more numerous, and if the tallness were hereditary, they would have it. Of this generation again the tallest would be more successful, and so the strain would be gradually improved. There is obviously no need to suppose that the food shortage was so great that only the adults with very long necks could get enough to eat, as some critics have done. Over several generations a quite small advantage could have a noticeable effect.

It will be seen that Lamarckism and Darwinism are not incompatible. But the results of genetics reduce Lamarckism to a factor of very little or no importance in heredity. As we have seen in Chapter XII, inheritance is by the genes, which reside in the nuclei of the germ-cells. Variations are brought about either by rare and unpre-

NAKED-NOSED WOMBATS

The marsupials of Australasia have developed on lines remarkably parallel with those of the Old World mammals. The wombat with its chisel-like incisors, parallels the larger rodents. This particular type is a native of Tasmania.

dictable changes in the genes themselves, or more frequently by their shuffling and recombination during sexual reproduction. Suppose that men always have red hair and women black. Cases of such a linkage of various characters are very well known. Then, as far as these signs go, there are only two sorts of mankind possible, red-haired men and black-haired women. But if shuffling of the genes is possible then in any generation some of the paternal inheritance may be interchanged with some of the maternal, so that some red-haired women and black-haired men would be produced. The species is now more variable, and therefore has a better chance of meeting the demands of natural selection. The whole biological significance of sexual reproduction seems to be that, during it, recombination of genes takes place, and the variability of the species is greatly increased.

Now, there is a very great deal of evidence that the heredity of any organism is controlled almost entirely by its genes. And there is no evidence whatever, or only of the most doubtful kind, that changes produced from the outside, as it were, can affect the genes at all. It seems that the control is entirely one way. The genes control the body, and not *vice versa*. Consequently, we must now regard the action of natural selection as a weeding-out of certain disadvantageous gene combinations or gene complexes.

It is known that the genes of any one individual are not completely separate and determinate entities, one controlling hair colour, another the number of digits per hand or foot, a third the shape of the ear-lobes, a fourth the correct formation of the skull during development, and so on. There is a mutual interaction going on which may be very slight or very profound. It may make no difference whether one particular gene (say for a paper-thin shell in a snail) meets in the same gene complex or genotype another particular gene (say for no bands on the shell instead of five), or, on the other hand, the resulting interaction may be so great that the effects are unpredictable.

There may be suppression, reduction, enhancement, or alteration of the character. Since many, perhaps all, genes each control many characters throughout the body, the possibilities which may result from a mutation of one gene may be very great. On the other hand, of course, there must be a reasonable amount of constancy, otherwise the genotype is at the mercy of every new mutation.

When an individual carrying a new gene mates with another, the novelty will be found in some of the offspring in association with genes derived from the second parent. During a few generations it will be tried out, as it were, in various differing genotypes, and since it will be modified by them in different ways, selection will favour those modifications of it that are most advantageous.

In this way, useful genes will be selected in particular genotypes in which they

AVOIDING DETECTION

The bittern, when alarmed, stands absolutely still with head raised. Its colour blends with the reeds and helps to make it invisible to its enemies.

ANIMAL CAMOUFLAGE

The young red deer makes use of the play of sunshine to protect him in his leafy retreat. His bright dappled markings blend with the light and shade of the forest.

can make themselves felt even in a single dose. That is, they will be dominant. And unfavourable ones will be allowed to continue only in genotypes in which their actions are nearly or wholly suppressed. That is, they will be recessive and can show themselves only when present in a double dose, the corresponding dominant then being absent since there can be only two versions of any particular gene in one genotype. When an animal with two doses of the recessive (homozygous for it) is produced, it will be at a great disadvantage. But in any interbreeding population, large numbers of individuals may carry one dose only of a recessive gene (that is, they are heterozygous for it) and show no ill effect; and there is always the possibility that other genes may modify it usefully, or external circumstances will change and there will be some advantage in it, in which case the homozygous individuals will enjoy the advantage first.

Now we can see a most important connexion between genetics, the study of heredity, and ecology, the study of the relationships between the species in their struggle for life. When new mutations occur, they will be spread most rapidly in a small population, in which there will be a high probability of homozygotes being produced. In a very large population, the likelihood that two heterozygotes will meet may be very small; but since there are far more animals in which mutations can occur, the members are likely to be heterozygous for many different genes. That is, the sort of genetic constitution an animal has depends very much on the size of the breeding population into which it was born. Now the numbers of a particular sort of animal may fluctuate widely because of disease, a sudden increase of predators, change of climatic conditions, or various other reasons, and the study of these variations is part of ecology. It is believed that small populations may be able to change much more rapidly than large ones, which however, can modify themselves for a particular mode of life more accurately and finely.

We have now possible answers to the first and fourth criticisms of Darwinism. The answer to the fourth is simply that it is right, and Darwin's theories of heredity were wrong, which means that we must modify our ideas on natural selection, but not abandon them completely. The answer to the first criticism is that natural selection is a passive agency, and variations are in-

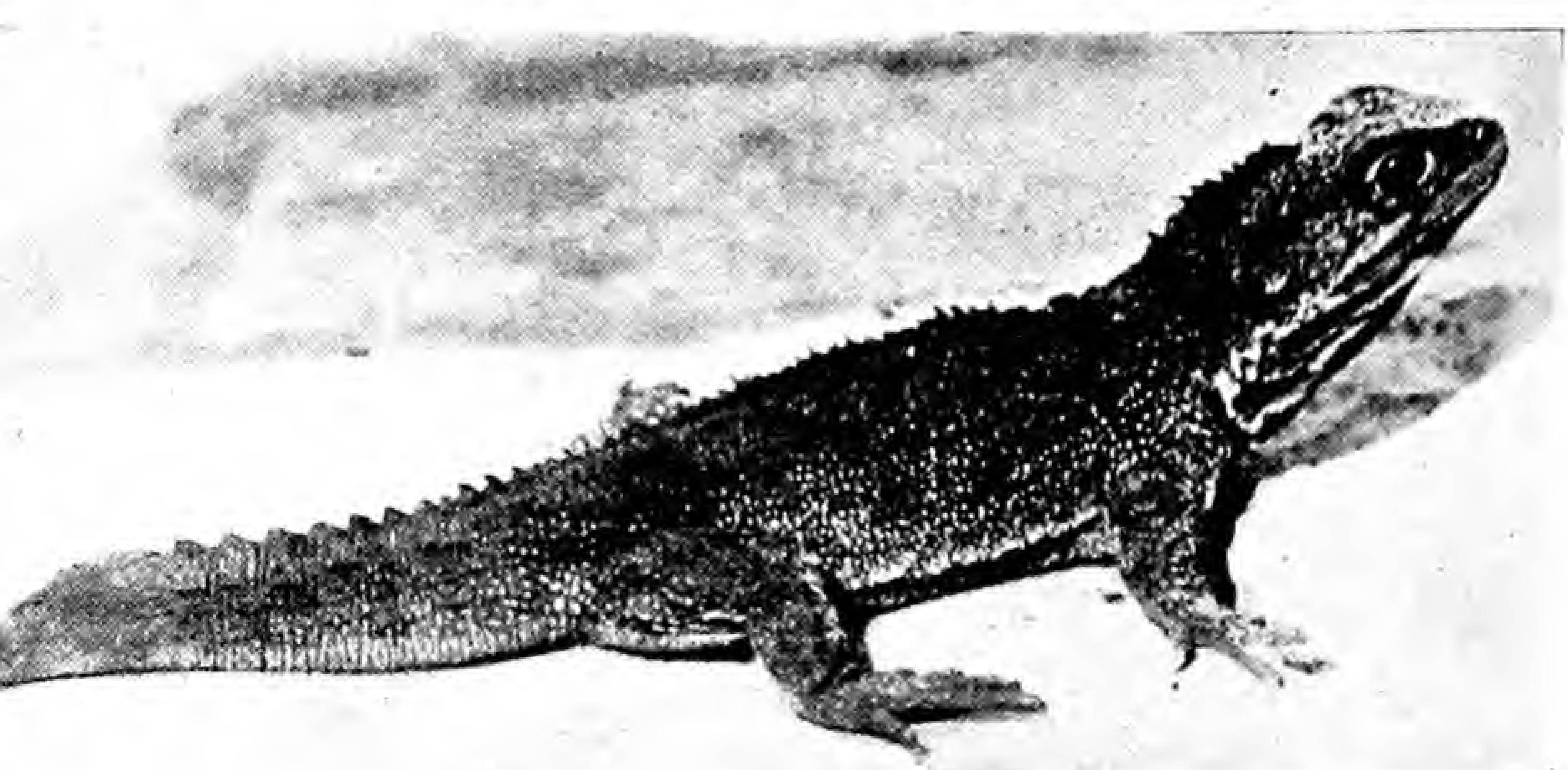
deed spontaneous and random; but the action of the two together produces direction. A new mutation appears in a way about which we know almost nothing except that its frequency can be raised by irradiation with X-rays, heat, etc. The effect of natural selection is to stabilize it in that genotype where it is of the greatest use. Natural selection has what might be called a sharpening effect upon changes, favouring and enhancing as well as discouraging and deleting, and allowing a reservoir of variation to remain within the race at the expense of producing a few unfortunates in each generation.

It is also possible that we have a reply to the third criticism—the rarity of connecting links between major groups. There are three parts to this reply, depending on what one considers a major group. The first is aimed against those people who maintain (particularly with respect to man) that the reason why the links are missing is that they were never there. It was given by Charles Kingsley in *The Water Babies*. "And no one has a right to say that no water-babies exist, until they have seen no water-babies existing; which is quite a different thing, mind, from not seeing water-babies; and a thing which nobody ever did, or perhaps ever will do." And, later on, "You must not say that this cannot be, or that that is contrary to nature. You do not know what nature is, or what she can do; and nobody knows . . . That is a very rash dangerous word, that 'cannot'; and if people use it too often, the Queen of all the Fairies, who makes the clouds thunder and the fleas bite, and takes just as much trouble about one as about the other, is apt to astonish them suddenly, by showing them, that though they say she cannot, yet she can, and what is more, will, whether they approve or not."

The second answer is well known, and fairly generally admitted. It is a reminder of the imperfections of the fossil record. Only animals whose hard parts were buried in mud, silt or dust are at all common as fossils. Except in very rare instances we have no knowledge at all of the very important evolution of the worms, which appear to have been ancestral to the Arthropods on the one hand and the Molluscs on the other, that is, to the greater part of the animal kingdom. And worse, in the earliest rocks which contain fossils we find remains of animals which are referable to relatively highly developed groups in the animal kingdom. The very early sedimentary rocks which were laid down while they were evolving, are lost, and those that we have contain at the best only the history

LINK WITH THE PAST

The tuatara lizard is the last remaining representative of a group of reptiles long extinct. It is found in New Zealand and is strictly protected.



ONE OF NATURE'S CURIOSITIES

The echidna, a spiny ant-eater, is another apparent freak, being one of only two egg-laying mammals. It has a pouch in which the eggs are laid and the young reared.

of the last quarter of evolutionary progress, if that. The only great group in which we have a reasonably complete set of fossil forms is that of the Vertebrates. It is hardly surprising that the history of the more ancient groups is not to hand. But it is true that there are many points in vertebrate history where links are unknown, but might reasonably be expected. The link required to connect across the very small gap between primitive mammals and their reptile ancestors is unknown, but in general one often meets lines of specialized forms, all obviously converging backwards in time, but the species required to join them all, the exactly ancestral stock, is not known.

This brings us to the third answer, which is, as mentioned above, that it is at least possible that small populations can alter throughout much more rapidly than large ones, in response to changing conditions. That means that it is most unlikely that there ever were huge herds of the most primitive mammals or of other very primitive groups at any one time on the earth. If that were so, the chances of some of them becoming fossils and being preserved are greatly reduced, and might be negligible. This is only a tentative answer, but it is supported by experimental studies on small populations in the wild, and is open to further investigation. Perhaps one of the most promising developments in genetics is the recent application of mathematics, to determine under what conditions and with what rates genes having a particular advantage will spread through populations of a particular size.

Various objections have been brought against the genes as material for evolution, and these must next be considered. It would be no good patching up the holes in one theory with another that is threadbare itself. The three principal objections to the governing power of mutations on evolution are on the score of their rarity, triviality, and frequent bad effect. It is found, in those animals and plants that have been most completely studied, that the rate of mutation varies but is always extremely low. One sport may occur in about a million normal individuals. Secondly, many known mutant genes contribute only slight effects to the organism as a whole, since they control only small details of colour-pattern, or small anatomical differences in not very essential organs, or slightly different rates

of physiological processes. And thirdly, when the effect of a mutation is not so slight as to be of little consequence, it is usually definitely deleterious to the organism.

In man, the known genes when not affecting eye-colour or the shape of the ear lobes, produce various forms of blindness, hereditary idiocy, malformations of the hands and feet, absence of limbs, and similar effects. On the basis of these objections it has been stated at various times that the genes cannot provide sufficient useful variation for evolution to take place, and that they are concerned only with the most superficial characters, the fundamental construction of the animal being inherited in some other way than through the chromosomes.

The enormous amount of work that has been done in genetics in the last forty years does not support these conclusions. As we have seen above, the variation in any population is due far more to the recombinations of genes already existing than to their continual change by mutation. It is their assortment and interaction that provide most of the variability. The triviality of their effects is usually pointed out in connexion with some attempt to explain the greater part of heredity on some other basis than that of the chromosomes. It has been suggested that that part of the protoplasm surrounding the nucleus or cytoplasm of the germ cell carries those character-determinants responsible for the fundamental organization of the animal or plant, and the nuclei are concerned only in its less fundamental characters, such as might determine its specific, generic or family differences.

It is not possible to reject this view completely because there is very good evidence that certain characters in some organisms are inherited through the cytoplasm and may vary to some extent independently of the nucleus. As an example, the plastids of plant cells, those bodies that contain the green synthesizing chlorophyll, are self-perpetuating. When on occasion they produce yellow offspring in one cell these are found in all its daughter-cells. In some cases it is the cytoplasm of the egg which exerts a marked effect on the course of development. This is the case in a common freshwater snail (*Limnæa*) in which the direction of coiling of the shell is so determined, though there is evidence that the nuclear genes of the mother do affect the cytoplasm. In other cases considerable cytoplasmic influence has been proved, but one must remember that if the trivial differences are due to genes, by the theory of evolution,

MALE AND FEMALE IMPALA

The adult bucks have large lyrate horns, which in the young males are but little developed, while the females are hornless. This distinction is characteristic of most deer.

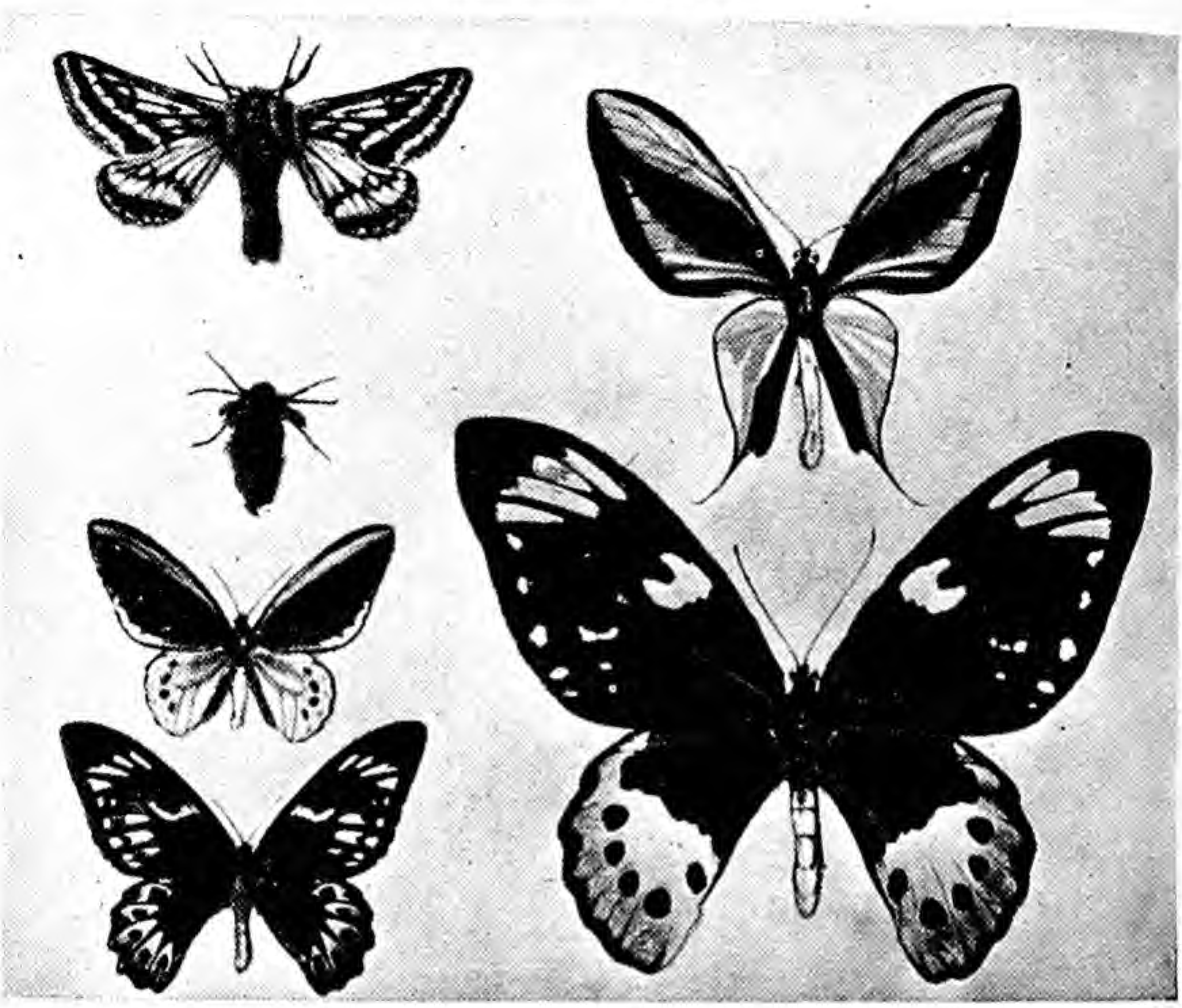
species-formation has started from the smaller differences, so greater differences in the cytoplasm must come later. Also, any organism is an exceedingly delicately balanced system of a multitude of interlocking chemical and physical processes. It is most unlikely that a sudden large random change would be anything but harmful. The chances of hitting a clock's works with a heavy hammer in such a way that its working is improved are remote, to say the least. And it seems very likely that the principal reason why only the trivial effects of genes are usually observed is simply that any alteration in the more profound effects is lethal.

Very many genes are now known, but the number of cases in which non-genic inheritance can be shown is small in comparison. Some genes have been described in which a quite profound effect can be seen. These are principally concerned with the proper development of the organism. In one strain of mice, for example, a gene has been found which affects the cartilage-rudiments of the skull in the embryo. When it occurs the cartilage rudiments do not join as they should to form the skull-floor, and this disturbance affects not only the skull-shape, but the development of the fore brain, and the habits and disposition of the animal. It suffers from hereditary hydrocephaly (water on the brain) and in comparison with normal mice has much the appearance of an idiot. The changes here are sufficient to be called profound, though not so great as to be lethal. Several genes are known which are lethal when together in pairs, though not when they are single. One such causes a yellow coloration of the coat of the mouse possessing it. This seems innocuous enough, but the homozygous or paired condition is lethal, and individuals with it are never born.

The generally bad effects of new mutations, then, need cause no surprise. Such mutations, unless bad enough to prevent the animal breeding, may be slowly spread in a population and by the modifying action of other genes be brought into a state of recessiveness. Man is a recent species, speaking in terms of geological time. He has been on this earth only about a million years or so. But in this time the actual numbers of individuals and of generations are quite high, even though breeding is slow. It is perhaps not surprising, therefore, that almost all the mutations that have been recorded are recessives. Only a very small proportion of dominants is known. The reason may be that the species as a whole is already partly accustomed to these mutations and has evolved in such a way that the gene combination of the race suppresses them when they appear.

Darwin's Theory

What, then, is the basis for Darwin's blending inheritance? It is that some characters are affected by so many genes (tallness is a case in point) that the effects of one particular gene can rarely be sorted out. The result is that the character is practically continuous. When it is a character which is also influenced greatly by diet and similar factors, the possibilities in any one case are almost endless. And since there are so many genes concerned it is in the highest degree improbable that any individual will receive a predominantly paternal or predominantly maternal make-up. It is far more likely that it will receive approximately half its height-controlling genes from each, and the net result will be intermediate. The same apparent continuity is visible when we study a long line of fossils. Quite often there is some difficulty in separating one species from another and even more in separating genera. There appears to be a slow and steady trend of alteration in various characters at once, and divisions into species and genera may appear very artificial. Here we are viewing a succession of generations viewed for so long a time that the effect of any particular gene, although large and simple enough to avoid any appearance of continuity, is not large enough to be conspicuous when the long-term trends are being considered. But in one such case it has been possible to show that there are discontinuities in the apparently smooth change, though they are only made clear by statistical analysis. This has been done in a study of the gradual evolution of the feet of the horse, and the effect of a mutation that took place millions of



EXAMPLES OF SEX DIMORPHISM

Male and female of some insects show striking differences. The female of the belted beauty moth (top left) is smaller than the male and has no wings. The other two pairs of butterflies show diversity of shape and size. In each case the male is above, the female below.

years ago in a long-extinct species can now be seen.

As an example of genetical work in the field, a very interesting series of observations by Dr. E. B. Ford on a colony of the marsh fritillary (*Melitæa aurinia*) may be taken. This colony of butterflies was very isolated, and had been collected from or closely studied for nearly fifty years. The numbers after being high for several years began to fall and, for a long period, the butterflies were very rare. One of the reasons for this decline was that the caterpillars were attacked by parasites. In the next four years, however, there was a rapid increase, so that the butterflies became abundant again, and remained so, increasing slightly, until the observations were discontinued. But butterflies collected in the second period of abundance are definitely, though only slightly, different from those of the first period. Individuals in both these periods vary very little. During the rapid increase, there was a most remarkable degree of variation. "Hardly two specimens were alike," writes Dr. Ford, "and marked departures from the normal form of the species, both in size, shape, and colour, were very common. A high proportion of these were deformed in various ways, the amount of deformity being closely correlated with the degree of variation. When the rapid increase had ceased these undesirable elements practically disappeared, and the species settled down once more to a comparatively uniform type, which, however, was recognizably distinct from that which prevailed during the first period of abundance."

The interpretation of these observations

appears to be as follows. During the first period of abundance the species was in equilibrium with its environment. The numbers produced in each generation allowed for a sufficient proportion to reach maturity and breed, the rest succumbing at different times through many different causes such as predators, accident, parasitism and so on. For equilibrium to be produced, since each butterfly lays considerably more than two eggs, the pressure of eliminatory factors must be fairly high, and individuals showing some variation at any stage in the life-history were not likely to survive, the chance of any immediately useful variation occurring being very small. Consequently, little variation is seen. In the next period, eliminatory factors became much more intense, and the numbers decreased in each generation, until the butterfly was very rare—perhaps so rare that the parasites had very great difficulty in finding new individuals to attack, and themselves became exceedingly rare through lack of food. As a result of this and probably other factors as well, the elimination-pressure was reduced, there was a rapid return to abundance, and since selection was not so fierce, far greater variation was permissible in this period. The species then attained equilibrium again but as a slightly different form. Dr. Ford remarks, "The increase in variation which was witnessed in this instance was so rapid, and the changes so marked, that it is difficult to believe that the processes of genic spread and improvement here postulated were wholly responsible for them. Whatever contributory cause may have been at work, it will none the less be seen how closely the observed facts followed the course of evolutionary progress which has been suggested as possible in fluctuating populations."

Differences between Species

There remains to be considered the second objection to Darwinism, that we know of neither intermediate forms between species nor incipient species. In this connexion also, a very great deal of work has been done since the beginning of the century, and it is difficult to summarize it adequately. More is known about the genetics of groups of related species of plants than of animals. In general, it seems to be true to say that the difference between species and between varieties is a question of degree. Varieties differ with respect to a few genes only, some of which, however, may be very striking in their effects, as in the case of albino races. Species seem to differ in respect of a large number of genes.

By some irregularity of cell division in the course of reproduction a plant is produced which has more than the parental number of chromosomes, usually a multiple of the normal (diploid) number. For example, in the large genus of the docks (*Rumex*) a few species have only twenty chromosomes per nucleus, others forty. The curled dock (*Rumex crispus*) has sixty, the great water dock (*Rumex hydrolapathum*) has 200, and different individuals of another species may have forty, sixty or eighty. If doubling up is sufficient to disturb the balance of the genes, so that the offspring cannot breed with the parent form, we have in effect a new species. If not, we have a variety only. A well-known case in which a new species has arisen by similar means is that of *Primula kewensis*. This primula was produced by crossing two others, *P. floribunda* and *P. verticillata*. The result was a hybrid, sterile apparently because the two sets of chromosomes, one from each parent, were too different to act as equivalent sets, so sexual reproduction could not take place. But occasionally there arises a form in which both sets are doubled, and segregation can now take place. It is self-fertile but (and this is a most important point) it is sterile to both of its parents. This form is apparently a true new species.

In such a case as this we have species-formation almost at a single bound. But this method is not general. More usually there is a gradual divergence, and the genotypes become progressively more and more incompatible. Since any gene may have very many diverse effects apparent in both the anatomy and physiology (the structure and the functioning) of its possessor, sterility may appear after a very slight change of the genotype. The wonderful variety of dogs that have been produced, intentionally or not, points to an equivalent variety

in their genetic make-up; but there is no apparent sterility between any of them.

On the other hand, one species of a genus of fruit flies (*Drosophila*) is known in which there are two races differing slightly in their habits but indistinguishable by anatomical differences, yet they are not inter-fertile. Two other species of the same genus resemble each other most remarkably in their anatomy, but are unable to breed. These are extreme cases, but they do exist and force us to ask what exactly we mean by a species.

If inter-sterility is to be the final criterion, then the two races mentioned above are separate species, and many plants which can and do hybridize must not be called species, although they are almost universally regarded as such and do fill different niches in the ecological structure of the communities in which they are found. The question is very much under discussion, but whatever happens, the rigidity, hardness, and discreteness of older ideas on species and varieties have certainly been greatly modified. There is ample evidence of intermediates of all grades. A puzzling case is that of the carrion crow and the hoodie crow. The areas in which each species lives overlap only very slightly, but where they do, hybrids are found. This, interpreted strictly, would mean that both are good species, except in the overlapping belt.

Neutral Differences

There is evidence in some cases that certain differences between species may not be adaptive at all. They neither help nor hinder, they are just differences. It is believed that such differences may be by-products, so to speak, of genes whose importance lies elsewhere. As long as these additional effects are neutral, of course, selection will not affect them, but if circumstances change they may become useful or detrimental. In the latter case, if other actions of the same gene are definitely useful, then selection will favour those individuals in which the detrimental effects are more or less completely suppressed.

It was stated above that in species-formation two races begin to differ more and more, until complete sterility is produced. But, it will be asked, how can this come about? If the original population was interbreeding freely, if a sudden mutation occurred that produced incipient sterility, the first individual in which it acted simply would not breed, or if its breeding was difficult, its offspring would be at a disadvantage and probably the strain would die out before pure-breeding (homozygous) lines could be established. This is a most important point which is still partly in dispute.

What is agreed is that by some means or other some part of the original freely interbreeding and more or less uniform population must be separated off to form a second interbreeding group. The effects mentioned before in connexion with the sizes of populations will then come into play, and if the two differ in size, as is likely, they will tend to differ in genetical make-up also. And the random occurrence of different mutations in the two will also have some effect in producing diversity. It is well established that animals or plants from one population, which become separated from it, give rise to races or species showing progressive differences. Thus birds which have colonized islands at different distances from their native mainland tend to form local races, and then species, on them, if constant immigration is not going on. This separation and consequent differentiation is the cause of the production of the remarkable floras and faunas peculiar to certain individual oceanic islands as mentioned before. The greater the barrier between the island and the nearest mainland, the greater are the special features that the island's populations show.

Changes through Separation

It is considered by some that physiological isolation can split populations in an effective way. Thus it might be possible that different strains of caterpillar in a species of moth might prefer slightly different sorts of foodplant. If this resulted in an effective separation as far as breeding-times and habits went, then new species might be brought about.

But there is a large group who consider that geographical isolation is probably by

far the more important. If different herds of deer, for example, tend to visit and then live in different valleys in a mountain range, differences will develop. A few adventurous individuals that cross a river at a time of exceptional dryness might colonize a new region and then be cut off. All such happenings would provide conditions of segregation, suitable for inducing variety and then species-formation.

It must be remembered also that there may be barriers in what seems a uniform population. It has been shown that animals such as lizards may never travel very far from their holes; hence many interbreed only with near neighbours. If there is a particularly large number of them on one patch of stony ground, and very few others for some distance, then we have isolation which may be only slight or very nearly complete.

To sum up, we can say that Darwinism as modified by genetics, is the principal theory of the mechanism of evolution that is in use in biological investigations today. Its great merits are that it accounts for a huge number of observations, it points the way to further investigation of apparent exceptions, very many of which have been shown to be only apparent, and it gathers together data from all the sub-sciences of biology and unifies them into an integrated science.

We have been examining Darwinism all along from a scientific viewpoint. It should be remembered that it, and biological science, and indeed all science, is open to criticism along certain lines by philosophers and others. They offer other theories of evolution, not necessarily contradicting Darwinism, but always transcending it, in which some great creative mind or purpose is recognized that seeks to realize itself through evolution of which it is the moving principle, or alternatively, seeks to create other intelligent beings for their own sakes. Such views are in many cases very respectable and very ancient. They were well known in Darwin's time, and by some were set up in opposition to his theory. But as they are metaphysical doctrines, and therefore cannot be investigated by scientific methods, they do not concern us here.

Test Yourself

1. What are the three main points in Darwin's theory of evolution?
2. Give three or four examples of animals which show adaptations to a particular mode of life, and say how these animals are related to one another.
3. Briefly describe how the marsupials of Australia illustrate so well the phenomenon of adaptive radiation.
4. What important contribution did Alfred Russel Wallace make to the theory of evolution by the ideas expressed in his book, *Island Life*?
5. What is Darwin's theory of sexual selection?
6. Explain the very long neck of the giraffe, first in terms of Darwin's theory, and then in terms of Lamarck's theory of evolution.
7. What are the chief imperfections of the fossil record?
8. What are the three principal objections to the idea that mutations play the leading part in bringing about evolution?

Answers will be found at the end of the book.

EDGE OF THE WOOD

Plants are dependent upon light and moisture and we usually find among all plant communities one or two dominant species more abundant than the rest. Here the bracken and blackberry are the dominants, while the centaury and St. John's wort have just managed to straggle upwards. On the ground, grasses and other small plants struggle for survival.

CHAPTER XV

ECOLOGY AND THE BALANCE OF NATURE

In the early days of the revival of interest in zoology and botany, about two hundred years ago, much attention was paid to the life histories, habits and behaviour of living creatures, and many facts were noted, some to be overlooked and forgotten for a century or more. Much of this work was anecdotal; the observations were curiously interesting but disconnected, largely because other branches of biology and related sciences had not yet progressed far enough for reasons to be seen and connecting links to be discovered.

Then interest swung to classification; then to comparative morphology (comparison of the forms of living things), embryology, palaeontology (the study of fossils), and evolution. Later it swung to cytology, or the structure of cells; and for a hundred and fifty years, in the rush of new knowledge, the living animal or plant was almost forgotten. Biology was in danger of becoming a study only of dead animals and dried plants.

After the beginning of this century a change set in with a sudden revival of interest in physiology, in the inheritance of characters, both of which studies required living animals and plants, and in the relation of living things to their whole complex environment. This latter branch of biology is now usually called Ecology. It somewhat resembles the old Natural History in its insistence on living creatures, but it is more accurate, more critical, more concerned with measurement, and more constructive. It has also at its service all the progress that has been made in the previous century in classification, morphology and physiology; and also, as will be seen later, in geology, geography, climatology and meteorology.

Ecology, then, is the scientific study of living things in relation to their environment, and this latter includes not only the inanimate factors of geography and geology, soil, slope, height of land, depth of sea; and of climate and weather; but also the animate environment of all other living things which impact on each other directly or indirectly. In ecology, zoology and botany are closely interwoven and cannot be separated.

Environments

First let us make a survey of the extent and variety of the inanimate environments that are available for living things.

The total land surface of the earth is about 197 million square miles, of which 141 million (71 per cent) is water and 56 million (29 per cent) is land. Of the land about one-tenth is at present under ice or snow. The amount of water locked up in this way in ice-caps and glaciers is sufficient, if all melted, to raise the present level of the oceans by over a hundred feet. Since the total amount of the ice cap has varied greatly in geological history, the level of the oceans has also varied inversely to the amount of land ice.

Of the land, about 70 per cent is under 3,300 feet (1,000 metres) above sea level; only a very small area is above 13,000 feet (4,000 metres); and the highest peak is about 29,000 feet. In the sea the distribution of level is very different, only about 13 per cent is less than 3,300 feet deep, and the greatest area, about one-third of the total, is between 13,000 and 16,000 feet. A few depths of over 33,000 feet have been recorded. The volume of the sea is approximately 328 million cubic miles.

The most important chemical factors which affect the environment from a biological point of view are, on land, the composition of the soil (for example, the presence or absence of lime, causing soil to be alkaline or acid); and, in the water, the amount of salt, which causes the great

POND-WATER LIFE MAGNIFIED ABOUT ONE HUNDRED TIMES

Photograph of a remarkable glass model of plant and animal life, such as is found in one half inch of pond water. The cup-shaped bodies are the traps of bladder-wort, a flesh-eating water plant. Many simple algae are seen attached to the large plant stems.

division between the fresh-water and the salt-water environments. Geographical and geological factors such as these are normally subject only to very slow changes.

The physical factors are more numerous, more variable, and of greater importance in determining the majority of the habitats and so, indirectly, the types of animals and plants that survive.

Since the heat of the sun is the source of energy for all life on this earth, the first physical factors that we must consider are the number of hours of daylight and the intensity of radiation, both of which of course affect the temperature of the environment.

If the earth's axis were at right angles to the plane of its track round the sun, the poles would always receive their light and radiant heat at an extremely low angle and would be cold, while the sun would always be vertical to the equator. There would be no seasons and all latitudes would have twelve hours' day and twelve hours' night. Owing, however, to the angle of the earth's axis we get the change of seasons and the varying length of daylight. At the pole there is a change from continuous day in

summer to continuous night in winter; while at the equator the length of daylight and darkness vary only by a few minutes throughout the year. The average amount of radiant heat reaching the earth's surface about the latitude of London is more than six times as great in summer as in winter, and in the tropics the average amount is more than double that received in southern England. So we have, ecologically, the fundamentally important factors, increasing cold towards the poles, the long polar winter nights and summer days, and the fact that when it is summer in the northern hemisphere it is winter in the southern. This latter fact is closely associated with the problem of migration in birds.

Land Temperatures

The highest air temperatures recorded on land are about 135 deg. F., but the surface of black soil or rock in the sun can go well above this. The lowest is about 90 deg. F. below zero, that is, over 100 degrees of frost. In Great Britain the extremes are approximately 0-100 deg. F.

If you go down in the earth, the temperature rises at the rate of about 1 deg. F. per 50 feet. Up in the air temperature falls so that in Britain above about 6,000-8,000 feet the air is usually below freezing point. On land the fall in temperature is about 1 deg. F. for each 300 feet rise above sea level. The occurrence of frost is an important factor in determining the distribution of many plants.

In the sea the changes are much less extreme, ranging only from about 29 deg. F. to 86 deg. F. (—2 deg. C. to 30 deg. C.). In land-locked areas and small ponds the surface temperatures may be higher, and of course there are occasional hot springs.

On land rainfall is the next most important physical factor, and this ranges from no rain for many years, as in parts of the Sahara, to over 500 inches per year in certain tropical mountain areas. The seasonal distribution of rainfall is of great importance, and in many tropical countries the changes from wet to dry and back again are the chief seasonal effects. Rainfall may differ greatly over a short distance, particularly, for example, on the two sides of a range of hills. In England the rainfall varies from an average of about 20 inches in the eastern counties to nearly 200 inches in the mountains of Wales and Cumberland.

In cold areas the rain falls as snow and this has special effects, such as protecting the soil beneath, and the animals and plants therein, from very low temperatures.

The rainfall also determines the flow of rivers and streams, and is of course the source of all the fresh-water environments.

Other factors of importance are air and water currents and various combinations such as relative humidity, evaporation and condensation. All these may be grouped as climate and weather. Weather is the actual condition at any moment; climate is a measure of the average conditions and the range of variation over a long period. All are subject to change, even in the same locality, and these changes, which are of great importance ecologically, can be grouped as follows :—

(i) Short Period Changes.
  1. Irregular. Weather.
  2. Regular. *a.* Daily cycle.
     b. Annual cycle of seasons.

(ii) Long Period Changes.
  1. Periodic weather cycles. Sunspot cycle.
  2. Very slow changes in climate, such as caused the ice ages in Britain.

Most of the long range changes make little or no difference within the life of an ecologist, but they are of very great importance, as they often determine which animals or plants are present in a country, depending on its past climatic history. The ecologist must not take a narrow view of his subject, and must remember that the flora of the British coal measures is as important biologically as, say, the lepidoptera at present found in Hertfordshire.

Let us now turn from the variety of habitats to the variety of living things that may occupy them. We classify these into animals and plants, with a few primitive forms whose position is intermediate or uncertain; but ecologically they are all inseparable.

The number of different kinds or species

which we already know is very great. The flowering plants of the world are not likely to fall short of 200,000 different kinds, to which must be added the ferns, fungi, yeasts, bacteria and so on.

Number of Species Compared

In the animal kingdom the number of species is even greater, dominated by the insects. In this last group the number of species already known is nearly half a million, and the total number in existence must be not less than two or three millions. In other groups the numbers are large, but not so spectacular. For example, the birds of the world, which are possibly more completely known than any other single group, include about 20,000 species.

In Great Britain, with an area of about 80,000 square miles, there are recorded at present about 1,500 species of flowering plants, about 33 ferns, about 3,000 fungi, less than 50 land mammals, about 425 species of birds, but over 20,000 species of insects, including 2,000 moths and over 3,000 beetles. The insect species outnumber all the other living things.

Next consider the number of individuals in these species, for the study of the size of populations and their changes and balance is one of the most important branches of ecology.

In plants it is not always easy to decide where an "individual" begins and ends, especially when you get vegetative reproduction; so let us take animals and start with man, who is, to the ecologist, one of the animals inhabiting the earth.

There are believed to be over 2,000 million human inhabitants of this world, and the number is, in most countries, steadily rising. In fact, a gigantic ecological problem is facing the United Nations Food and Agriculture Organization. In Great Britain there are now about 45 million, but a hundred years ago the number was only about 19 million, and in the year A.D. 1600 less than five million. The British population is still rising very slowly, but is expected shortly to reach a peak and perhaps to fall.

In England and Wales there are estimated to be about 60-70 million nesting land-birds in the spring and early summer; nearly twice as many as there are human beings. These belong to about 150 species, of which the two commonest are the chaffinch and the blackbird with about ten million each. At the other end there are about eight species with fewer than ten individuals, but of course these are more common in other countries.

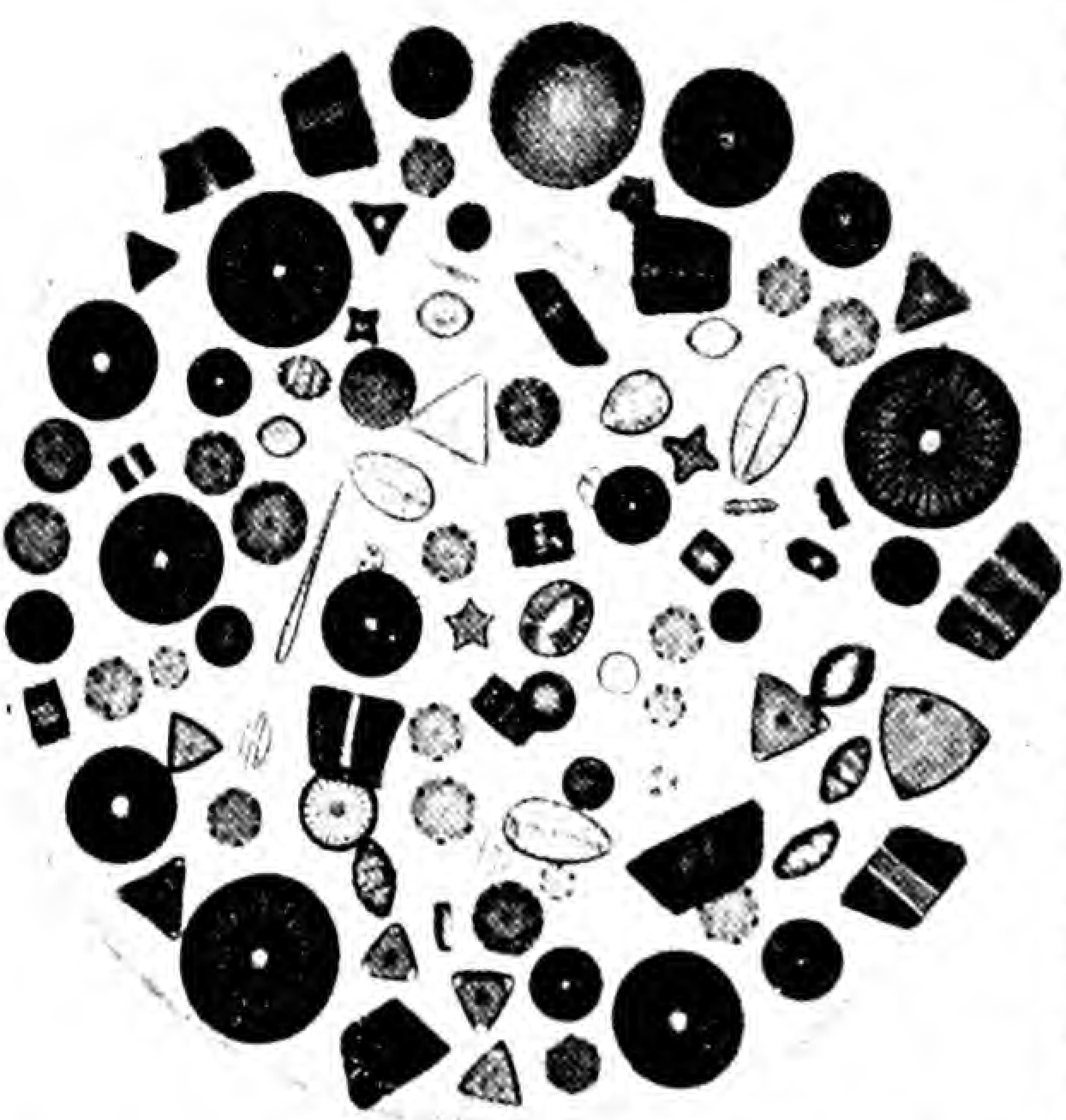
In the soil of one acre of land in England there may be anything from 50 to 200 million insects, occasionally even more. For a single species, for example, the injurious wireworm, there may be ten million or more per acre. Since an acre contains about six and a quarter million square inches this means that soil may contain more than ten insects per square inch of surface under the climatic conditions of Britain. If we take this as a possible average figure for the land of the world (excluding the 10 per cent under ice), allowing the deserts to be below and the tropical forests above, there would be in the world at any one moment about ten million million million insects.

When we turn to the bacteria the numbers are so great that our calculations for insects appear to be quite trivial. In a single gram of soil (about 1/30 of an ounce) there may easily be a thousand million bacteria and, since the soil to a depth of 10 inches weighs about 1,000 tons per acre, the numbers of bacteria may be nearly a million million million for each acre of land.

Teeming Life

In the sea we get similar astronomical figures. The number of diatoms off the coast of California varies from 100 to over 100,000 per litre of water, and there are 750 litres for each cubic yard. In the South Atlantic a low figure for the total number of plankton (floating small animals) per litre is 5,000 and the number may reach over 100,000.

At the other end of the scale we have species that exist in very small numbers. These cases are always difficult to prove; rarity in museums is not a proof of rarity in numbers. An animal or plant may be rare in one country but abundant somewhere else. Frequently the true habitat of



DIATOMS

Group of diatoms, highly magnified. These tiny marine plants have two-valved siliceous shells and abound in salt or fresh water. They have a wide variety of forms.

a so-called rare species has not yet been discovered. Still, there are definite cases; for example the St. Kilda wren, unknown except on this island beyond the Outer Hebrides, has been estimated by careful survey to exist at present in only between 60 and 70 pairs. It is easy to see that such a low number of individuals brings with it special dangers of extermination.

Fluctuating Numbers

The ecologist is, however, not merely interested in the number of individuals of any one species living at any one time. An even more fascinating and fundamental study is the change in numbers that occurs both in space, from one locality to another, and in time, from day to day, from year to year and from century to century.

One of the most remarkable cases of rapid change in numbers is found in the lemming, a rodent which lives in the north of Europe, particularly in Lapland, and which extends further south in the mountains of Scandinavia. At intervals, usually of three or four years, the lemmings increase in abundance and overflow from the hills into the coastal areas of southern Norway, sometimes reaching Oslo. The numbers in these mass movements may reach hundreds of thousands, but a year later none are to be seen.

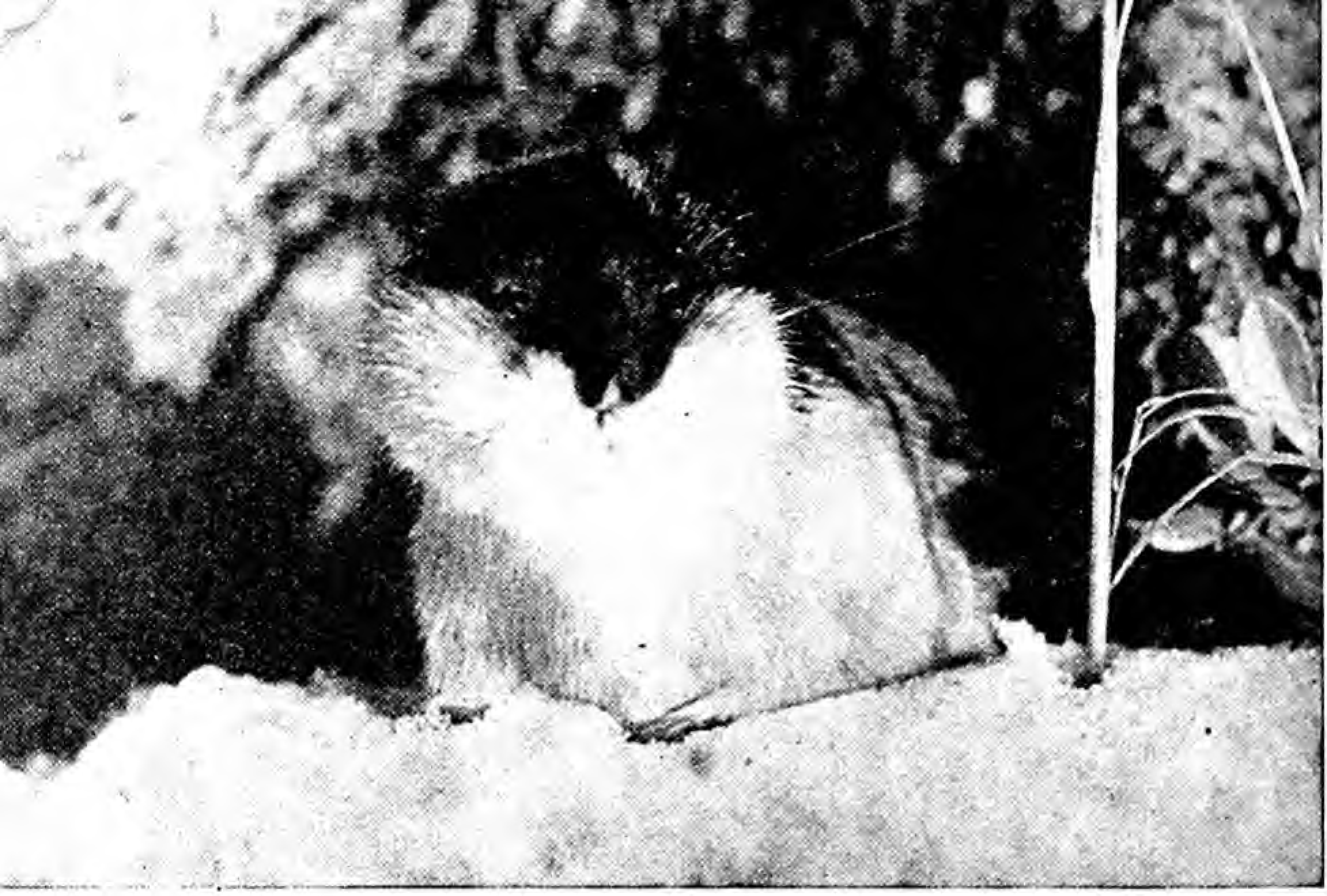
Mice and voles are subject to similar great outbreaks, and in 1890-1892 the latter were in such numbers in south-west Scotland that crops and pastures were severely damaged. In the spring of 1892, sheep and lambs had to be supplied with fodder brought in from outside the plague area.

The "snow-shoe rabbit" (*Lepus americanus*) in North America is subject to violent fluctuations in numbers and it has been stated that in some places they have decreased from over 3,000 per square mile to practically none in less than one year. The lynx, which largely preys on these hares, has similar fluctuations closely following those of its prey.

When settlers first went over to North America, one of the most remarkable sights was the flights of hundreds of thousands of passenger pigeons which were said almost to darken the sky. As recently as 1888 they still existed in millions. Today there are none left alive.

In counts made of the grubs of a small fly which damages wheat in Britain, the number in five hundred ears has varied from 1,000 to 28,000 in two successive years: that is to say, in two consecutive generations.

The rapid spread of the rabbit and the



LEMMING NEAR ITS BURROW

Small mountain-dwelling rodent. When urged by the migratory instinct, the lemmings descend in thousands to the lower levels and make their way in a direct line to the sea. Many drown, but as they are prolific breeders some always survive to carry on the species.

prickly pear in Australia, after the first introductions, is well known; and in Britain we can see at the present moment the steady increase of the grey squirrel which was introduced from North America.

By catching insects in a moth trap in U.S.A. an entomologist obtained in one year over twenty-three thousand individuals of one species. In the following two years not a single specimen was captured, although exactly similar trapping had been carried out.

Power to Multiply

The power of a species to multiply, sometimes called by ecologists the "biological potential," depends fundamentally on two factors, the fertility or birth-rate, and the length of time between reproduction in successive generations. This is balanced by the death-rate before maturity, which is sometimes called "environmental resistance."

Man produces normally one to ten young, and the generations are 18-30 years apart. The death-rate is relatively low, and both birth-rate and death-rate are lower in the so-called civilized countries.

Many insects lay up to 1,000 eggs, and the length of the life cycle is seldom more than a year; often only a few weeks. A queen bee may lay up to half a million eggs, a codfish over four million, and an oyster over a hundred million.

In the plants conditions are somewhat different, but many annual plants produce thousands of seeds, for example, the spotted orchis (*Orchis maculata*) is said to average about 56,000 seeds per plant. Some trees can live for a thousand years, producing seed throughout the period. Fungi produce spores by the thousands of millions.

In the bacteria, diatoms and certain unicellular animals, we get still another condition where increase in numbers is by growth and division into two. There is no "death" after reproduction; each death is the end of that line of life. In such cases the power of the species to multiply is determined only by the time between successive divisions. As this interval in bacteria may,

under favourable conditions, be as short as fifteen minutes, it will be seen how rapidly a population can change.

Any species must be at any time either stable in numbers or increasing or decreasing. If we take an example from the sexually reproducing animals, conditions will be stable if, for each pair in one generation, there will be one pair surviving to maturity in the next generation. The species will be increasing if more than one pair survive and decreasing if fewer. Thus, if the population is stable, only one pair can survive out of all the eggs or seeds or young produced by one pair of parents during their life. For example, if a nation of men produce on an average three children for every male and female in one generation one of them must die without offspring if the population is to remain steady. The death-rate, before maturity, must be 33 per cent.

If the female of a pair of insects lays a thousand eggs, then a death-rate of 99.8 per cent is necessary to prevent a rise in the population. If two out of every thousand survive we get stability; if four survive, the population will double in one generation; if only one survives, the population will be reduced by a half. Thus we see that a change of death-rate (before reproduction) from 99.6 to 99.9 per cent will make all the difference between a population doubling and halving.

Extreme Cases

In the case of the cod and the oyster, the flowering plants and the fungi, conditions are even more extreme. In the diatoms, half the population must be destroyed in the average interval between two successive divisions in order to keep a steady population.

It is important to note that various causes of death may have very different effects on the stability of a population. The two types generally recognized are those which tend to keep the numbers average, and those which do not have this effect. For example, if any animal becomes unusually abundant, its enemies will find food abundant, and will in turn increase in numbers, and will exert an even greater pressure. On the other hand, if the species becomes for a period rare, its enemies will have greater difficulty in finding food, general predators will seek other food, and the death-rate of the species will be greatly lowered. Thus the effect of parasites and predators, disease and food supply is to bring the population back to normal.

Effect of Weather

On the other hand, the effect of severe weather conditions, such as a killing frost, is usually to destroy a large proportion of the population, whether it is above or below normal at the time. If the population should be already below normal, it may make it more difficult to return to normal. We have already mentioned, in the case of the St. Kilda wren, that very small or very scattered populations may have considerable difficulties in mating or, in the case of plants, in the pollen of one plant reaching another of the same kind. This type of death-rate may tend to accentuate departures from the normal.

So we see that changes in numbers of animals and plants depend fundamentally on fertility, on length of life from birth to maturity, and on the death-rate before maturity. Life after reproduction has ceased is, except in the rare cases of colonial animals, biologically a waste. Many animals die immediately after reproduction, and in some cases the act of reproduction may be the direct cause of the death of the female or the male.

One other point to note in connexion with the changes of numbers of animals in any particular locality is the power of concentration or dispersal by movement. This may be active, as in migration, or passive, when, for example, seeds, spores or small insects are carried long distances by wind.

Causes of Fluctuations

It follows that the immediate causes of fluctuations of numbers of animals and plants are to be found in all those factors which affect fertility, length of life or death-rate ; and so we return once more to the impact of the environment on the animal.

We have already dealt briefly with the inanimate factors, such as weather and

DEEP-SEA LIFE

Some of the millions of microscopic animals which live in the lower depths of the sea fighting and devouring one another until they themselves fall prey to larger beasts. Many of the deep-sea crustacea are luminous and have large well-developed eyes.

climate, so let us now consider the ways in which plants and animals affect one another when they come into contact.

The most important relationship is that of food—the eaters and the eaten, the parasite and the host, the "crop" and the "pest." Each animal or plant is constantly, but usually unconsciously, striving to get its food and not to be eaten.

The chlorophyll-bearing plants, which obtain their energy from the sun, are the only group which can exist without some source of organic matter, that is to say, without some other living source of matter. They use the energy from the absorbed radiation to build up complex proteins and organic compounds from the chemicals in the soil and air. A green plant can be grown in a water solution of relatively simple inorganic chemicals, provided that it has sufficient light.

All other living things, animals and plants, are directly or indirectly dependent on the so-called green plants. Where no light penetrates, as in the deep sea or in caves, no community can survive without an external source of organic matter. Bacteria and fungi grow at the expense of the green plant when it is alive and after it is dead. The roots, as they decay in the soil, form the basis of other life; in fact, decay is a living process. The leaves are eaten by herbivorous animals, which in turn are the hosts of parasites, and are eaten by carnivores. Caterpillars and other insects eat the leaves, stems and roots, and are in turn destroyed by internal and external parasites, or are eaten by birds.

In the surface layers of the sea there are to be found countless millions of microscopic plants which are eaten by millions of microscopic animals, which in turn are eaten by countless thousands of larger beasts. As all these die, they sink to the deeper layers of the sea, far beyond the range of light, and provide the organic material and energy for the extraordinary forms of life which are to be found at great depths.

It has been calculated that a single copepod, which is a minute crustacean barely a tenth of an inch in length, will eat about 120,000 diatoms a day. Yet copepods form the main food of many of our largest

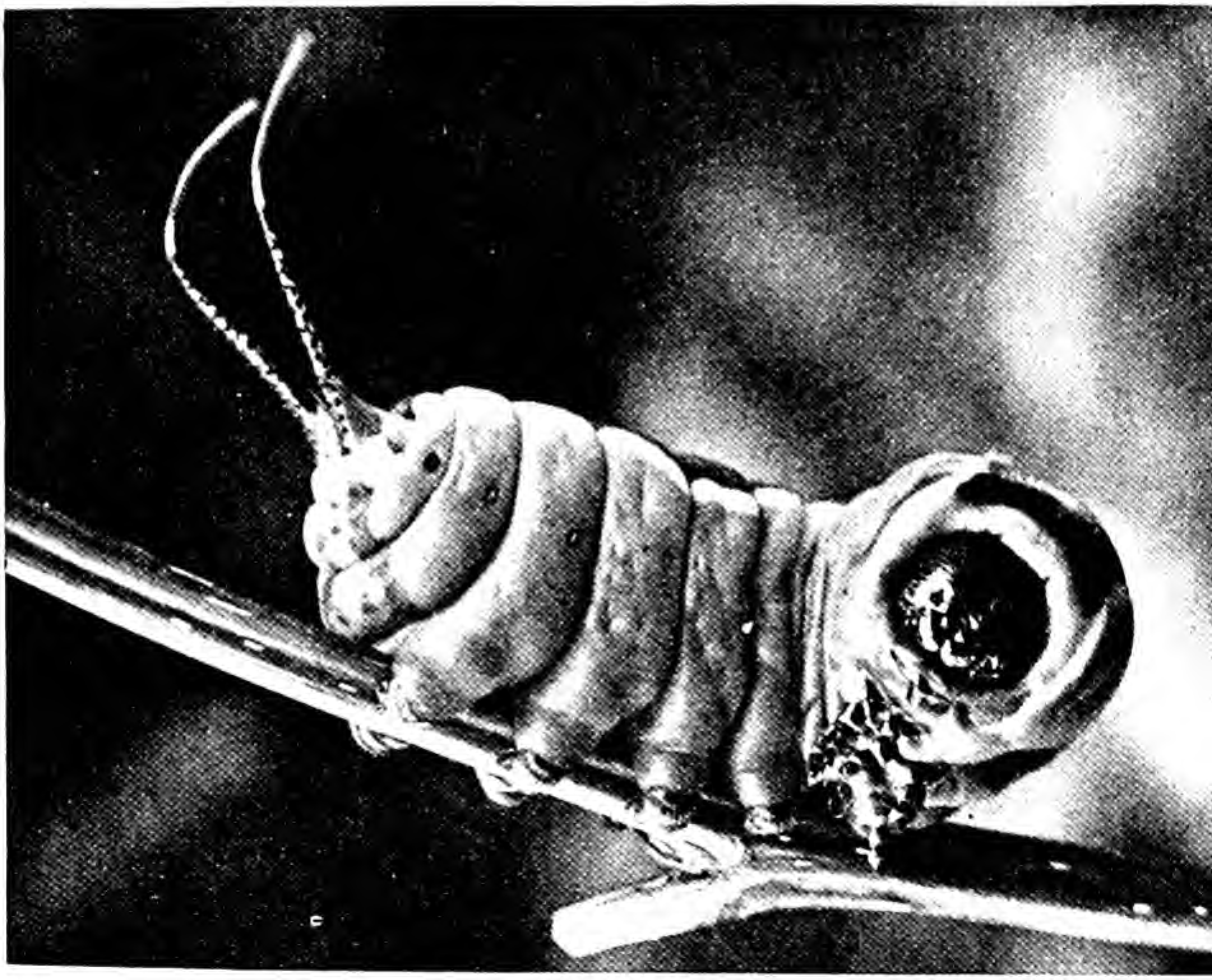
whales, and within the stomach of one whale there was found over 250 gallons of them—just a single recent meal.

Out of the struggle to eat and not be eaten arise all the various complex adaptations for safety and approach. The close resemblance that many animals have to their surroundings; the insects that look like sticks; the changes of colour of fishes according to their background; animals that go white in winter; and frogs that look like leaves; all this is a part of ecology.

There are also many far less obvious food relations. Different foods may alter the fertility of the "feeder." In the process of feeding on a fruit, the animal may help to distribute the seed of a plant; plants may react to injury by producing galls, and so on.

Equally interesting are the relations within and between species, which are of the nature of co-operation and competition.

In social insects, such as ants and bees, and in the family life of higher animals, and in the social life of man, we get co-operation between the different individuals of a species for mutual benefit. The whole group of plants which we call lichens is in reality a close association of two entirely different groups, fungi and algae, in which the algae provide chlorophyll and so the power of absorbing radiant energy. Many plants are unable to establish themselves satisfactorily from seed without the presence of



TERRIFYING POSE

In the struggle to eat and not be eaten, animals adopt various protective devices. The puss moth caterpillar when alarmed adopts a pose which possibly inspires its enemies with fear. Its front view looks sinister enough and from its tail protrude red, waving filaments. It can also eject drops of formic acid as a defence.

ANTS GUARDING APHIDES

A colony of ants provides an interesting study of community life. The ants use the aphides as men use cattle and " milk " them for the honeydew which they exude. The small insects around the large aphides are their parthenogenetic young.

particular fungi which live in close association with their roots. The leguminous plants have nodules on their roots containing bacteria: these bacteria are able to synthesize nitrates from nitrogen and so make the latter available to the plant. Many insects are unable to digest their food without the presence of minute unicellular animals in their gut: destroy these protozoa and the insect dies of starvation in the midst of plenty. The whole mechanism of plants producing nectar and flowers for insects in return for the service of cross pollination is a typical example of co-operation between species in the plant and animal kingdom.

When the association of two dissimilar organisms is mutually beneficial it is called symbiosis. When advantageous to one side without harming the other it is called commensalism. When it is harmful to one of the two partners it cannot be called co-operation, but comes rather into the character of parasitism.

Competition, apart from direct food relations, also occurs continually between nearly all species which come into contact with one another. Competition for the available space, for food, for shelter and for the particular niche which each species wishes to occupy. As a result, all the animals and plants in any association or community are in a state of uneasy balance. It is interesting to note that random samples of a large number of individuals made from a wild mixed population show a mathematical order in the relative abundance of the different species. In such samples there are always more species with few individuals than with many. Thus sixteen thousand moths captured in a trap during four years at Harpenden, about twenty-five miles north of London, included 240 species: but of these 75, or nearly one-third, averaged only one individual a year or less, and only

34 species had over a hundred. One species had 2,350 individuals, which was about one-seventh of the total captures.

The ecologist is particularly interested in the classification of the different environments from a biological point of view, in listing the different species which occur in each environment and in seeing what part each species plays in the community. Let us take, for example, the sea, and note how it would be considered. We can recognize the following main divisions:—

(1) The animals and plants of the sea floor, known as the benthos. This is subdivided into a littoral zone, round the coasts and to a depth of a few hundred feet, and a deep sea zone extending to the greatest depths yet dredged.

(2) The animals and plants which are free in the water, or pelagic. These are subdivided into the plankton, the small animals and plants which float or can move only very short distances; and the nekton, the animals which swim.

Littoral Life

The littoral plant life includes the green and the brown seaweeds seen on the sea shore at low tide. The animals include molluscs (limpets, mussels and periwinkles); burrowing worms; anemones; sponges; crabs; shrimps and other crustacea; and small fishes which frequent the rock crannies and pools. The character of both plants and animals depends on the configuration of the coast line, if steep or shelving, cliffs or sandbanks, great or small tides, and so on. The study of the shore association alone is a life's work for a keen ecologist.

It is curious to note in passing that although the insects are far above all other groups in diversity of species on land and in fresh water, yet in the enormous salt-water environments there are scarcely a dozen species.

On land there is a greater variety of habitats and more rapid changes. In cold temperate regions we get long summer days with sufficient light and warmth to allow the development of a considerable vegetation, followed by long nights with intense cold. The animal life that wishes to take advantage of the summer vegetation must face the problem of winter starvation. Two methods are found to overcome this difficulty: hibernation and migration. In hibernation, stores of reserve fat are usually accumulated during the season of plenty, and are used up slowly during the winter when metabolism is at a low level, and in normally warm-blooded animals the temperature of the body falls considerably. Some of the smallest animals have the power of drying up almost completely and may remain for years in that state, but are capable of renewed life when conditions are again favourable.

The other alternative is to leave the area on the approach of winter and move to warmer climates. This is the great phenomenon of migration, which is so conspicuous in many of our birds, some of which, like the swallow, by crossing the equator twice a year seem to have solved the problem of living in eternal summer.

There are, however, as in all branches of ecology, some curious exceptions. A most striking one is the Emperor penguin which swims southward to the Antarctic continent early in the winter, and lays its eggs and nourishes its young in the middle of the polar night with temperatures 60–70 deg. F. below zero.

Forest Habitat

Another habitat with definite physical characters and special forms of plant and animal life is a tropical forest. Here we get moderately high rainfall combined with absence of low temperatures, and, as a result, a great variety of large trees with their tops forming a canopy perhaps a hundred and fifty feet or more above the ground. There is little ground vegetation, except in clearings, owing to the small amount of light which penetrates the canopy, but many creepers whose trailing woody stems may be several hundred feet in length. Insect and bird life are not abundant at ground level, but more so above. Owing to the great difficulties of observation, little study has been made of life in the upper layers of a tropical forest, but it is a fascinating problem for the ecologist.

The woodlands of Britain show similar problems on a smaller scale, but with a

more definite sequence of winter and summer, fewer different trees and more undergrowth, as the canopy is not usually so dense. Definite "layering" is found and the birds feeding near the ground are different, at least in proportion, from those in the middle levels and those at the tree tops.

All these habitats can be, and have been, further sub-divided almost *ad infinitum* and certainly sometimes *ad nauseam*. One has only to examine the distribution of moss on tree trunks in a cold temperate climate to see that the north side of a trunk has a different environment from the south side.

We have mentioned the change of season in the English woodland. Such changes are of special ecological interest, and particularly for the way in which events follow one another year after year in a moderately regular sequence, but always under the influence of recent weather conditions. This branch of ecology is called phenology. The horse-chestnut always breaks into leaf, and shortly after into flower, in the spring; but what determines the particular date each year? In early years the tree is already in bloom by the 1st of April, while in late years the leaf-buds may not even have broken by that date. Weather affects both the plants and the insects that feed on them. Normally the insect finds its host plant in approximately the correct conditions when it is ready to feed or to lay eggs. But if unusual weather conditions prevail the two may be put out of step and the results may be disastrous for the insect.

Apart from seasonal changes there are other slower changes often brought about by the living creatures themselves. Scarcely any plant or animal association is stable. Many pass through a slow sequence of living forms which is known as a succession. This is most easily seen on the edge of woodlands which under entirely natural conditions are usually either advancing or receding. Even when the forest has reached the stage of large trees, changes may slowly occur. Sometimes the seedlings of one species cannot grow well underneath the parent tree, while other seedlings can. Thus as the old trees die they are replaced by different kinds.

In natural conditions such changes may take centuries, but often when man interferes we may see the succession developing more rapidly. In 1892 a small heather moor in the south of Scotland was visited by a few pairs of black-headed gulls. They were protected by the owner of the land, and fifteen years later there were over 3,000 pairs nesting.

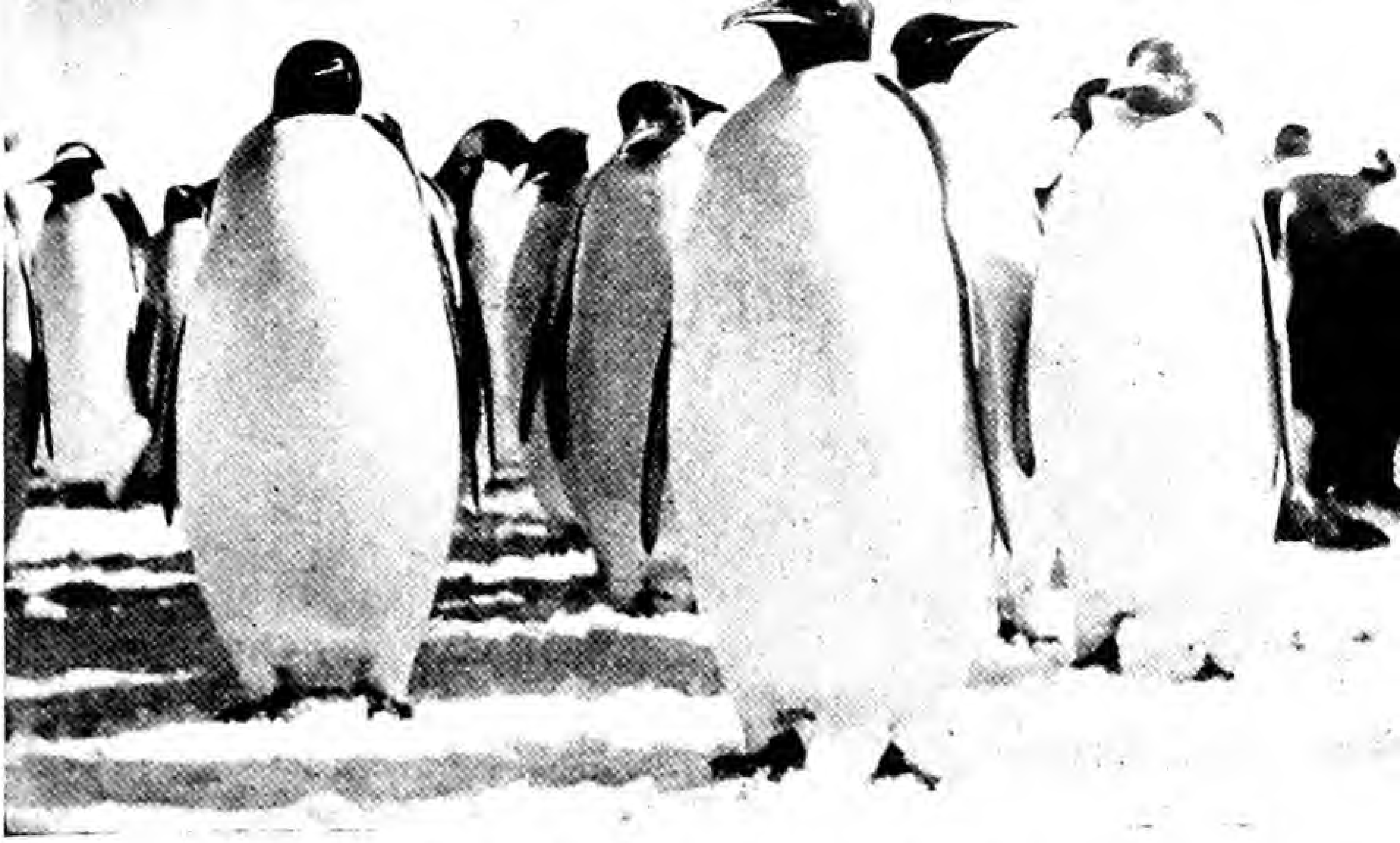
The trampling of the ground and the droppings from the birds had caused a complete change in the vegetation; first from heather to grass, then to rushes, and then to docks. Pools of water had formed amongst the vegetation. The grouse had gone and were being replaced by teal. Then the protection of the gulls ceased and the ground slowly but steadily returned to its original state as a heather moor.

Applied Ecology

The study of ecology is of enormous economic importance to mankind. In fact the whole of agriculture is a form of applied ecology. The farmer tries to get the best possible environment for his crops. He selects healthy seed from the best varieties, puts the optimum amount of seed in the ground at the best time of the year, and prevents competition by cultivation to destroy the weeds. Furthermore, he applies chemicals to make the soil richer, or to kill fungi and insects which may destroy the plants when they grow.

In the fishing industry ecology is again of major importance. Some years ago, for example, the problem of winter-kill of fish in some North American lakes was studied. It was found that when the lakes froze in the winter the water below the ice might become deficient in oxygen. As long, however, as light could penetrate through the ice, photosynthesis went on in the microscopic plants in the water beneath, and small amounts of dissolved oxygen were formed. If, however, *snow* fell on the ice it acted as a blanket, cut out the light, the oxygen of the water fell and the fish were killed. Thus the death-rate of the fish in winter depended more on snow than on ice.

In this brief survey of the field of ecology we have seen that it covers all the multitudinous relations between the living plants and animals and between these and their



EMPEROR PENGUINS IN THE ANTARCTIC

Instead of seeking a warmer climate at the approach of winter, the Emperor penguin journeys southward to the Antarctic, where he breeds and rears his young in the cold darkness of the polar winter, safe from molestation by predacious land mammals.

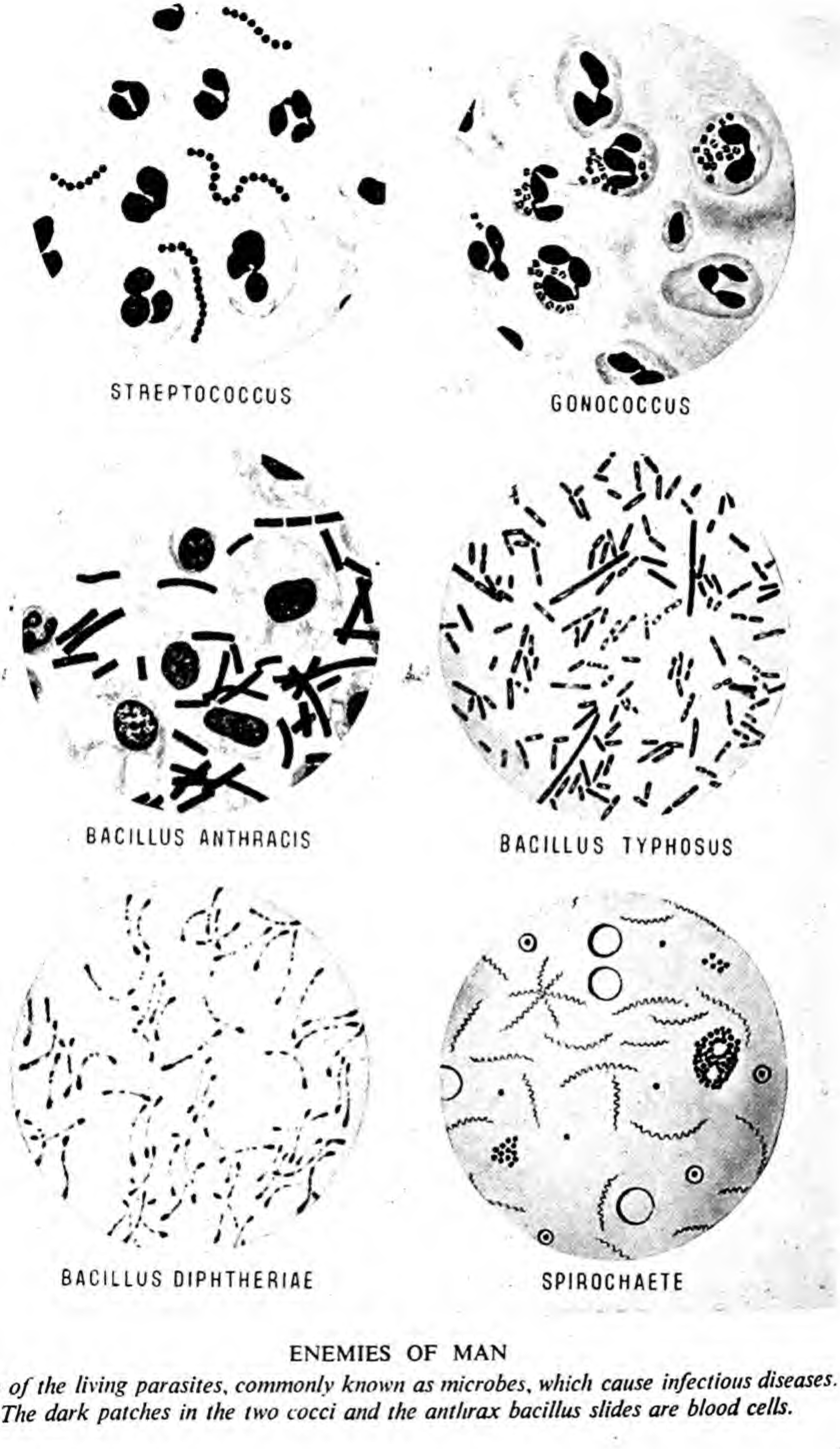
inanimate surroundings. It includes the effect of weather and climate; the fertility, length of life and death-rate of all organisms; the struggle for food and to escape being eaten; the effect of parasites and disease; the seasonal changes during the year, and the slow changes due to alterations in climate or to the living creatures themselves. It includes migration and drift, hibernation and aestivation (winter and summer sleep), fluctuations of population numbers, and a thousand other problems.

The ecologist can work in the laboratory with animals and plants under controlled conditions, where the complex factors of the environment can be analysed one by one. But his true place is in the field, observing, measuring, tabulating, photographing and mapping, thinking and planning; so that future workers can compare conditions in his time with those at a later date. The variety of problems is so great that there is room for all workers, amateur or professional, provided that they will be critical both in their observations and their interpretations, and accurate in their recording.

Test Yourself

1. What is Ecology ?
2. About how many different kinds of insects are there known to exist in England and in the world ?
3. How many small living plants and animals may there be in the upper layers of the sea ?
4. What are the three *fundamental* causes of changes in the numbers of animal populations ?
5. What are some of the *immediate* causes of changes in the numbers of animal populations ?
6. What are the conditions that lead to a stable population ?
7. What is the lemming ? and what is specially interesting about it ?
8. What is Phenology ?

Answers will be found at the end of the book.



ENEMIES OF MAN

Some of the living parasites, commonly known as microbes, which cause infectious diseases. The dark patches in the two cocci and the anthrax bacillus slides are blood cells.

CHAPTER XVI

MICROBE AND MAN

OUR knowledge and understanding of the world around us has been derived, in the first instance, as a direct result of the development of man's powers of observation. We observe by means of our senses, which you will have read about in Chapter VI. Our sense of vision has told us more of the world around us than all our other senses put together, but the eye, like the other sensory organs, has its limitations; one of these is the inability to focus on the retina images of very minute or microscopic objects.

Man's vision was much extended by the introduction of lenses, which enabled him to see more clearly things far away and things so minute as to be invisible to the naked eye. In Italy, early in the seventeenth century, Galileo was constructing telescopes and an imperfect form of compound microscope. With the former, Galileo began the modern study of astronomy, but his microscope was too inadequate to reveal objects of microscopic size. At about the same time, men in Holland were perfecting the technique of grinding lenses, and some sixty years later an able Dutchman, Leeuwenhoek, had made for himself a simple microscope which enabled him to see for the first time such minute objects as red blood cells and spermatozoa. By 1683, he described and made drawings of small animals, creatures as small as "one thousandth part of a louse's eye."

Leeuwenhoek's Microscope

His microscope consisted of a single small lens of very short focal length, which he ground himself, and fixed in a metal frame. Attached to the metal frame was a little platform, or needle, on which the material to be examined was placed, and which could be moved towards or away from the lens by means of a screw, thus bringing the object into focus. Leeuwenhoek was a draper and also a chamberlain of the Town Hall at Delft. He was constantly improving his skill and technique in grinding lenses and making microscopes, with the sole object of satisfying his great urge to investigate the secrets of nature. He is reputed to have made over four hundred microscopes in his lifetime.

The fortunate microscopist of today can buy, relatively cheaply, a beautiful piece of workmanship which is the product of many hands—the elaborate calculations of the mathematician whose formulae determine the shapes, number and spacing of the lenses; the laboriously acquired skill of the glass workers and lens grinder, and the precision engineers who provide the metal framework to house the lens systems.

Can you imagine the supreme joy of Leeuwenhoek, were he to come back to the world today and behold the modern microscope? Would he be mystified if he were told that the microscope's magnifying power was now limited only by the wavelengths of light? That ultra-violet light is used because of its shorter wavelength in order to push the resolving power of the microscope still further? Who can tell? But he would most certainly pucker his wrinkled brow if he were told of the electron microscope and the enormous magnifications to be obtained by its use.

A high-class microscope reaches its limit of magnification at about three thousand diameters, but with the electron microscope we may go with confidence up to fifty thousand, and perhaps up to two hundred thousand diameters.

The microscope opened the door to unsuspected worlds, not only a whole world of hitherto unknown life-forms, or micro-organisms, but hundreds of structural secrets too fine for detection by the human eye. First, the fluids of the body, such as the blood with its yellowish globules; secondly, the organs and tissues of the body, which the microscope revealed to be built up of myriads of cells, each organ having its own cellular pattern and, further, that

the structural pattern of a particular organ is almost identical from animal to animal. Hence was born the science of histology.

In order to make the fullest use of the microscope in this study, men learnt the trick of cutting very thin sections of tissues. Students of botany to this day learn to cut

ANTONY VAN LEEUWENHOEK

Inventor of the first microscope. He made a study of tiny organisms which he called his "little animalcules."

thin sections of plants freehand with a razor, supporting the tissue between two pieces of pith. This method was at one time used for the microscopic examination of animal tissues, but has now been superseded by the use of a microtome.

Pieces of tissues are removed from an animal and placed immediately in a solution of formalin, or salts of the heavy metals, or a mixture of both, which kills and fixes the tissues in as life-like a form as possible. The water in the tissues is then replaced by wax and finally little blocks of wax containing the tissue are cast. These wax castings are then fixed in the microtome and an automatic feed enables the operator to cut very thin sections of the tissue, which the wax prevents from disintegrating. Sections as thin as 0.001 of a millimetre (i.e., 1μ) may be so prepared and fixed to microscope slides for subsequent examination.

This is made the easier because the different tissues have the property of selectively absorbing dyes which enables the observer to differentiate cells, and even parts of cells. An extension of this technique is the identification of specific chemical substances, or structures, within the cell. Chapter I of this book could not have been written if there were no microscopes.

Mention was made earlier of Leeuwenhoek's little animalcules, or bacteria, which he observed in rain water, and later accurately described; he also drew many forms of bacteria which he found on his own teeth. His work on bacteria earned for him the title of Father of Bacteriology.

Classification of Bacteria

There is as yet no internationally recognized classification of bacteria. Research has been directed more to their physiology and the part they play in nature, than to cataloguing the enormous number of different recognized strains into genera and species. We may, however, attempt a rough classification of bacterial cells into three main types according to their shape :

1. Some spheroidal in shape, and called "cocci," such as streptococci, staphylococci or gonococci, etc.
2. Some cylindrical and called bacilli, such as bacillus coli, bacillus typhosus.
3. Those looking like a corkscrew, such as the spirochaeta pallida of syphilis.

The cocci are about one to two thousandth of a millimetre in size; the bacilli may be up to five thousandth of a millimetre long and about one-thousandth thick. (The viruses, most of which are too small to be seen with the ordinary microscope, are the subject of intense work these days, but our knowledge of them does not lend itself to a brief review as yet. We cannot with certainty define them as living objects; they seem to occupy a position intermediate between living and non-living matter.)

Relatively few bacteria are able to pro-

duce disease in animals or plants. Those that do are described as pathogenic, and those that do not as non-pathogenic bacteria.

Bacteria play a useful part in the economy of life on this planet. The chemical processes that are continuously taking place in the cells of animals are effected by substances known as enzymes. The activities of these enzymes during life are controlled and directed towards the well-being of the cell and through the cell of the animal as a whole. When the animal dies, the enzymes break down the protoplasm to ever simpler constituents. This breaking down is assisted by invading bacteria, and the end products of this disruption enrich the soil and make further life possible.

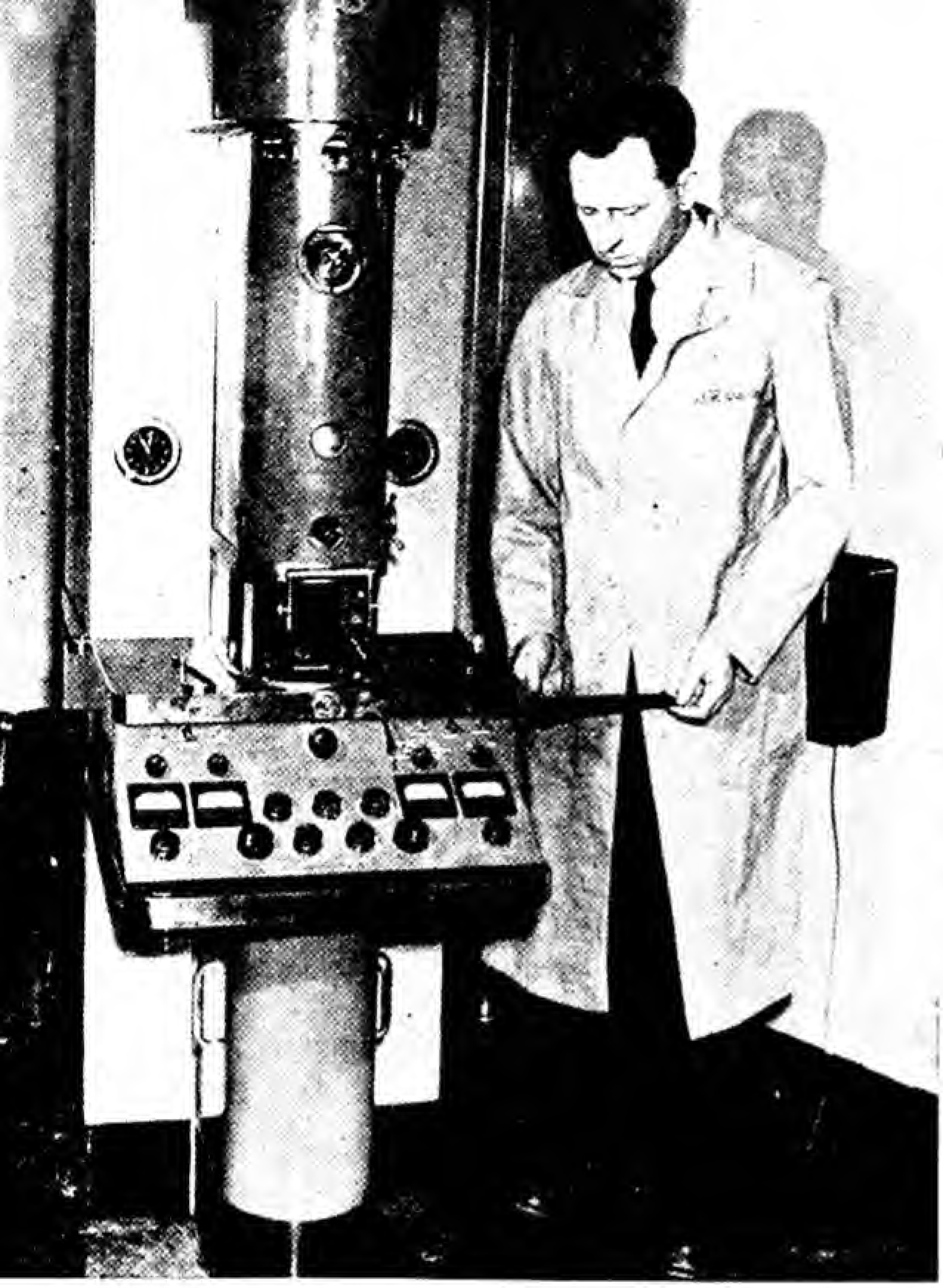
This power of bacteria to break down and liquefy organic matter is extensively used in the disposal of sewage, whether it be in septic tanks or on filter beds. In the former, most of the beneficial bacteria are anaerobes, i.e., bacteria which live in an atmosphere free from oxygen, while in the latter free oxygen is necessary to enable the aerobic bacteria to play their part. Under conditions prevailing in sewage beds, disease-producing bacteria which have been voided by human beings are largely destroyed.

In the soil are bacteria which are able to fix atmospheric nitrogen and make it available for plants to assimilate and build up the proteins necessary for their protoplasm. We find nodules on the roots of certain plants such as peas, lupins, etc., which when examined under the microscope are found to be teeming with bacteria. In some herbivorous animals, digestion is assisted by bacteria which break down the cellulose of plants and liberate materials which the animal's own ferments can then digest and make assimilable. There is now a good deal of evidence that certain of the vitamins (for instance, members of the B group) are manufactured in the alimentary canal of animals and human beings by bacteria.

Many industrial processes, such as the making of vinegar and acetone, are carried out with the aid of bacteria, and we must not forget their usefulness in the production of cheese. Thus, we see that many bacteria are used in the service of man, and these may, therefore, be called beneficial organisms.

That certain bacteria can produce disease is now such common knowledge that few realize how relatively recently this knowledge has been acquired. From time to time, through the ages, views have been put forward about the causation of disease, but none of these theories was based on

PUBLIC ANALYST AT WORK
Food testing in a public analyst's laboratory. The modern microscope plays an important part in safeguarding the community.



ELECTRON MICROSCOPE

By employing a stream of particles of electricity instead of a light beam this super microscope can magnify up to 200,000 *diameters as compared with a limit of* 3,000 *with an ordinary microscope.*

experimental evidence, which is the only criterion by which they may be tested and proved. The leper's cry "unclean" in biblical times is evidence of some small recognition of the contagiousness of disease. The serious epidemics of plague in the Middle Ages strengthened this view, but no measures of prevention, other than by isolation of the sick, could develop until the causative agents and the mode of their transmission were recognized and defined.

We have seen that bacteria were identified, drawn and described by Leeuwenhoek in 1683, but it required the genius of Pasteur, in the latter half of the nineteenth century, to prove that these organisms can produce disease. This proof was achieved by careful scientific work, in which he learnt how to isolate and culture pure strains of bacteria, and to investigate the effects produced by the introduction of these organisms into animals and man. Lord Lister was quick to appreciate the importance of Pasteur's discovery and he proved that the infection of wounds could be prevented by taking precautions to exclude the invasion of the wound by bacteria.

This extension of Pasteur's work by Lister has enabled surgery to advance to an unparalleled degree. Men's imaginations were stirred by Pasteur's discoveries, and many investigators turned to this new and profitable study of disease, and their efforts have brought incalculable benefits to the health and well-being of man and animals alike; yes, and even to the vegetable kingdom.

Bacterial infection may arise from contaminated food or drink, from the air we breathe, by direct contact with infected persons (or animals), or through the skin as in wounds or insect bites. How does the food get infected ? Spontaneous generation of germs, a popular view at one time, was proved impossible by the brilliant researches of Pasteur and Tyndall. The germs must come from some person or animal who is either suffering from the disease or who is a " carrier," that is, a person who has recovered from a disease, but who still carries the infecting bacteria within his body.

How Infection is Spread

Let us take a few instances: suppose a man is suffering from typhoid fever, we should find his faeces and urine teeming with typhoid bacilli; his bed linen, clothes and utensils are likewise infected. Suppose further, his faeces are deposited in an old-

JOSEPH LISTER

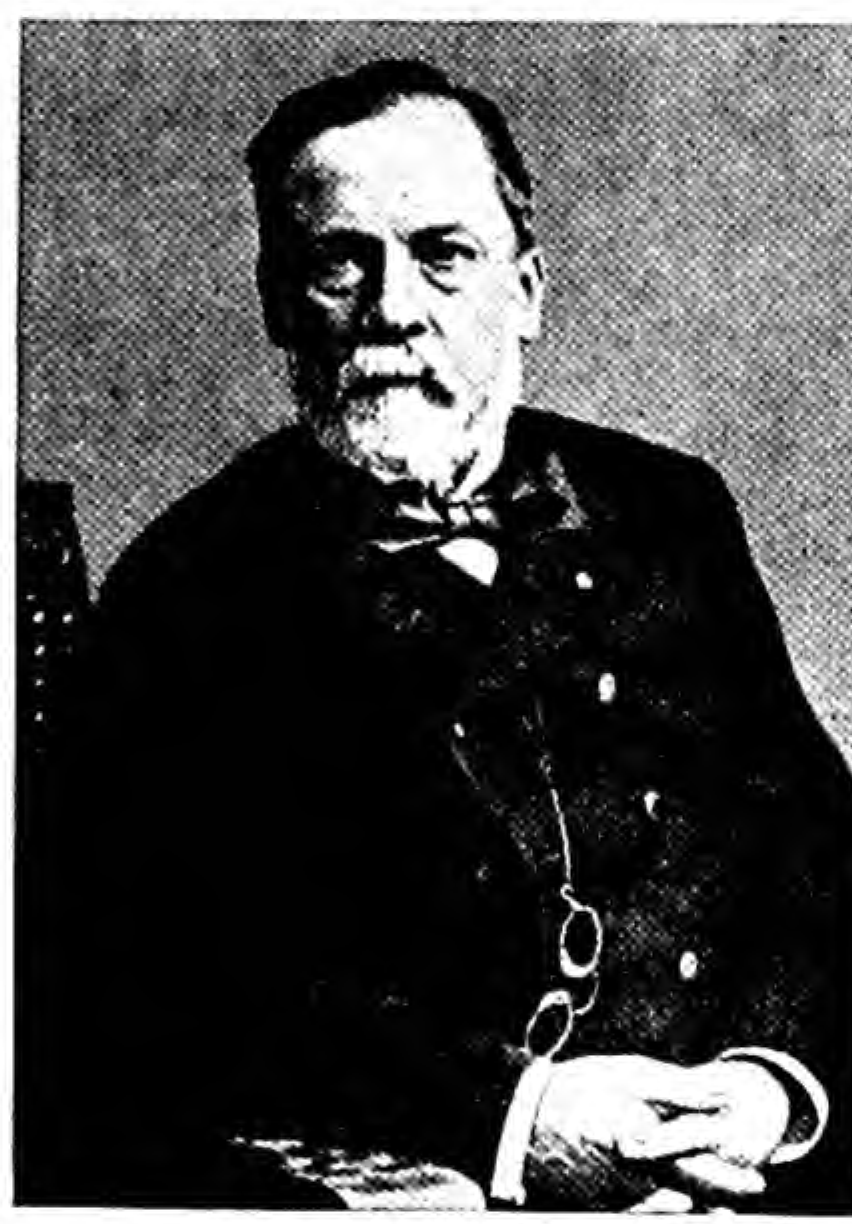
The great pioneer of aseptic surgery. Basing his work on the discoveries of Pasteur, Lord Lister revolutionized the art of surgery.

fashioned privy, flies would settle on them to feed or lay their eggs, carry bacteria away on their feet and next land, say, on a milking bucket; a cow is milked, the milk is pooled and sent off to the dairy. The milk remains warm and is a rich source of food for the typhoid bacilli, which multiply exceedingly, and unless the milk is sterilized many people would be exposed to infection.

Another possibility exists, the fluid in the privy may leak into a surface well, the water gets infected and is a source of danger, not only locally but over a wide area, if it be used without boiling for washing dairy utensils. The dangers of careless nursing are too obvious to need further description. Now, if the man recovers he may still harbour bacteria, and occasionally when he micturates, or defaecates, his fingers will pick up some of the bacteria, not numerous enough of themselves to do any damage, but if he handles food (without first carefully washing his hands) he passes the bacteria to the food, where they will multiply; and unless the food is sterilized by adequate heat, as in cooking, the consumers of the food are liable to infection. This is the usual way in which foods such as ice-cream become dangerous.

This example is of a disease affecting the alimentary canal, and because it is transmitted by the excreta of infected persons we could classify it and similar diseases, such as cholera, etc., as excremental diseases. (We will deal with methods of prevention and spread of disease later.) Let us now take an instance of an airborne disease, such as diphtheria. The infected person (or carrier) will have diphtheria bacilli in his nasal and bronchial secretions, and in saliva. When he speaks, or coughs or sneezes, droplets of the disease-carrying secretion are sprayed into the atmosphere.

If the air is dry, the moisture in the tiny droplets rapidly evaporates and a fine suspension of bacteria is left in the atmosphere. In wide open spaces, or well ventilated rooms, this suspension is rapidly dispersed and the danger considerably



LOUIS PASTEUR

Famous French chemist who discovered that fermentation is caused by bacteria.

HEAD OF A HOUSE-FLY

Dangerous insect upon which man must constantly wage war. It has six legs and carries the germs of many diseases on its feet. It sucks up food through its long proboscis with the aid of a muscular pump inside the mouth.

minimized; but in confined spaces the danger increases the nearer we get to the infected person. Diphtheria, tuberculosis, influenza, meningitis, mumps, whooping cough, measles and many other diseases are transmitted in this way.

Certain diseases are transmitted by actual physical contact with an infected person. Some skin diseases are passed on in this way and so are the venereal diseases, syphilis and gonorrhoea.

Insects play a large part in the transmission of a number of diseases. This they do by biting an infected person and thus infecting themselves. Future victims of the insect will not only suffer from the bite, but also from the disease the bite transfers to them. Mosquitoes transmit malaria in this way. Fleas are the carriers of plague; a human plague epidemic usually starts from infected rats—the rats die and the fleas from them hop on to men and infect them.

There are places in the tropics where this disease is endemic (that is to say, persistent in a locality), and rats from these areas may get aboard ship and so carry the disease to other countries; hence the precautions taken at ports to prevent rats from getting aboard or coming ashore. Formerly these diseases were stamped out by disinfecting the clothing, etc., by heat and thus destroying the vermin, but nowadays the introduction of D.D.T. has made it possible to disinfest the population of a whole town in a very short space of time, and so nip an epidemic in the bud—as happened at Naples during the late war. D.D.T. has similarly been a boon in destroying mosquitoes, which transmit yellow fever as well as malaria.

The seasonal incidence of disease is too complicated to discuss adequately here, but a little thought about what has been said above will throw some light on this difficult problem. For instance, in warm weather bacteria will multiply rapidly in a suitable medium, likewise flies will breed; the combination of these two factors readily explains such diseases as the summer diarrhoea of infants. In cold climatic conditions, human beings herd together in confined, and often ill-ventilated, spaces to keep warm, so we should naturally expect airborne disease to be more prevalent in winter.

Sewage Disposal

We are now in a position to deal with the precautions taken to prevent the incidence and spread of disease. Let us take the excremental diseases first. The problem here is to dispose of sewage in such a manner that the disease-carrying matter cannot contaminate man's food and water supplies, nor yet act as a breeding ground for flies, rats, etc. In a settled community, this is accomplished as follows: in the home, water closets are designed with a water trap which makes a seal between the sewage pipe and the lavatory; the pipes outside the house are provided with an air vent which usually opens at roof level. The sewage pipes are collected into main sewers which are then led off for disposal. (Rain water from roofs, roads and so on may open into these sewers or may have

its own sewers which drain directly into rivers, etc.).

If the town is near the sea, sewage is led off into the sea well off shore or, from an inland town, to sewage works or farms, where it is run into a series of filter beds. Here the beneficial bacteria break down and liquefy the solid matter, and harmful bacteria die out in an environment hostile to them. The water from the final filter bed is now sufficiently purified to drain off into streams or rivers. The general public owes a great debt to medical officers of health, sanitary engineers and inspectors, and legislators who have made our sewage disposal so efficient and safe.

Danger from Water

A plentiful supply of pure water is essential for life and health. Infected water has been responsible for many epidemics of dangerous diseases, such as typhoid and cholera, and until this was realized outbreaks were common. In India, many thousands die each year of cholera, which they have contracted from drinking water. The last big epidemic of cholera in England occurred about the middle of the last century and was responsible for over twenty thousand deaths. Towns are built on or near rivers for, among other reasons, a ready supply of water and also the disposal of sewage.

If infected sewage is discharged into the river, towns downstream will have their water supply fouled and outbreaks of disease automatically follow. Fortunately, rivers tend to purify themselves by the following means: (1) dilution by tributaries, (2) sedimentation, (3) sunlight, (4) shortage of foodstuff on which bacteria can live, (5) salts and other substances in solution in the water of some rivers which make it difficult for bacteria to live and grow. Obviously, however, water from rivers, lakes, and other sources must be purified before being drunk, if it is to be safe.

In civilized countries, we drink water from the tap without fear because we trust those responsible for our water supplies to do their work satisfactorily. This work consists of: (*a*) the clarification of water by sedimentation; (*b*) sterilization by means of a series of sand filters or else chemicals, such as chlorine (as little as one part in a million of *free* chlorine will kill bacteria within the space of one hour); (*c*) storage in reservoirs. Water from deep (or artesian) wells tends to be free from bacteria, for the earth through which the water has percolated filters off particulate matter.

Care must be taken to prevent surface water from leaking into such wells, for if it does it may carry infection in with it.

In America, laws have been passed which make it compulsory for all who are handling foodstuffs to be medically and bacteriologically examined before being allowed to work. The danger is especially great with individuals handling milk and milk products. The pasteurization of milk (i.e., heating milk for thirty minutes to a temperature of 145/150 degrees F. and cooling rapidly to below 55 degrees F.) is one method of getting round the danger. Sterilization of milk by boiling is even safer, but then the milk is not so palatable.

The prevention of airborne diseases is a much more difficult problem, for no matter what official action may be taken, so much

WATER PURITY TEST

All civilized countries today, where conditions permit, have complicated systems of water supply and sewage disposal. Another public analyst is seen testing water from the local supply system for purity.

INFANT RECEIVING DIPHTHERIA IMMUNIZATION TREATMENT

Diphtheria is an extremely infectious disease which at one time accounted for a high rate of mortality among children. Research workers eventually discovered a toxin which provides immunity from the disease without otherwise affecting the health of the recipient. This immunity is produced by inoculation and is looked upon today as a normal precaution.

depends on the individual. The main features for the prevention of this type of disease are :

(1) The provision of adequate cubic space for each individual and avoidance of overcrowding.

(2) Adequate (and preferably draught-free) ventilation.

(3) Windows big enough to admit plenty of daylight (most disease-producing bacteria are destroyed by sunlight, and even ordinary daylight is lethal to them, provided they are exposed long enough to it).

(4) Thorough cleansing of eating and drinking utensils.

(5) Personal precautions, such as covering the face with a handkerchief when coughing or sneezing, and prohibition of spitting.

Remember that in the operating theatre surgeons and others wear gauze masks to prevent droplets containing bacteria falling from their noses or mouths into open wounds during operations.

Immunity to Disease

By immunity we mean the complete (or partial) resistance of the host to infection by specific bacteria or bacterial products. This resistance can be classified as follows:

(1) *Inborn or congenital immunity*, e.g., some species of animals and their offspring are completely immune to diseases which kill other animals (or man).

(2) *Acquired Immunity*. A child born into this world is heir to numerous bacterial diseases. Sooner or later, it will come into contact with infective organisms. Sometimes, the contact will be a massive one and the child becomes ill, sometimes the dose is smaller, and unless the child be undernourished it may escape the disease. Later, further small infections present themselves and again the child escapes. Occasionally, it grows to adult life without having come face to face with the infecting organisms.

Now, if the child contracts the disease, and recovers, it is found subsequently to be resistant to further attacks of the same disease, and similarly the child who has several times been in contact with the disease is often resistant to the disease. A method exists of ascertaining whether an individual is immune or not to diphtheria. It is found by this method that the older the age group examined the fewer are the individuals susceptible to the disease; similarly, it was discovered for the same age group that children of poorer districts are more immune than children of better-class areas. (This is because gently nurtured children tend to be kept in bed if they have colds or symptoms of illness, and so do not infect their playmates.)

We know, therefore, that we can acquire naturally an immunity to disease either by having the disease (and of course recovering) or else by getting many small doses of the disease-producing bacteria.

Toxins and Antitoxins

Now, some bacteria kill by invading the body and destroying the tissues of the body, others by producing poisons which when absorbed are lethal. These poisons we call toxins. If we culture diphtheria bacilli, we find that the toxin is liberated into the medium; now, if the bacteria are removed or killed, the medium containing the toxin is found to be lethal when injected into a susceptible animal. In the blood of an immune subject there is a substance which is capable of neutralizing or antagonizing the toxin; this substance we call an antitoxin.

The chemical constitution of these substances is obscure—we know they are proteins, and also the type of protein, but until the chemistry of proteins as a whole advances we cannot clearly understand what happens when an antitoxin neutralizes the toxin. The antitoxins belong to a class of proteins found in blood plasma, called antibodies. Other members of this class are: (*a*) agglutinins, substances which cause foreign cells or bacteria to clump together or agglutinate; (*b*) lysins, proteins which cause foreign cells, or bacteria, to disintegrate; (*c*) precipitins, which precipitate colloidal matter.

Now, when the body acquires an immunity it does so because a specific and foreign substance (called an antigen) has entered it by one route or another. The

organism then reacts to the specific antigen by producing (after a lapse of time up to ten days) a specific antibody which circulates in the blood stream. The antigen need not necessarily be bacterial in origin, it may be egg albumen, pollen, foreign blood, and so on, but even so an antibody specific for the exciting antigen is produced. This technique may be used for identifying substances when straightforward chemical and physical means are incapable of finding a solution.

Persistence of Immunization

A specific antibody produced either by disease or by the injection of an antigen is at first present in a high concentration in the blood (called by bacteriologists a high titre); with the passage of time the amount of circulating antibody falls off, but never to zero. There is, however, an important difference between the reactions of a man immunized, say, twenty years ago and a non-immunized subject. If the antigen is again presented to the immunized man, his tissues immediately and without hesitation produce the right antibody to neutralize the antigen, whereas the non-immune person must wait seven to ten days before his body has learned the trick of synthesizing the specific antibody.

(3) *Artificially acquired immunity*. From what has been said above it will be seen that immunity may be artificially produced through the agency of human beings. To illustrate how this is done two diseases will be dealt with, diphtheria and typhoid. Diphtheria bacilli produce a toxin which kills the cells of the body with which it comes into contact, e.g., bacteria grow in the throat and trachea, the membranes of these structures die, become detached and may choke the child, or the toxin gets absorbed and destroys other tissues of the body. If the disease is not treated by antitoxins (see below) over thirty per cent of its victims die. Obviously, such a potent poison as diphtheria toxin cannot be used as such to produce an artificially acquired immunity; it must be weakened somehow or other before being used for such a purpose.

Early work showed that if the toxin be neutralized by antitoxin it may then be injected without causing much damage, but the uncertainty of the neutralization was a difficulty. Bacteriologists have learnt the trick of altering the toxin chemically so that it is still capable of acting as an antigen but incapable of killing cells. This is usually done nowadays by incubating the toxin with formalin and then precipitating the changed product with alum. The material is then standardized so that the subcutaneous injection of 0·2 c.c., and one month later of 0·5 c.c. of this preparation will produce an adequate immunity in the recipient.

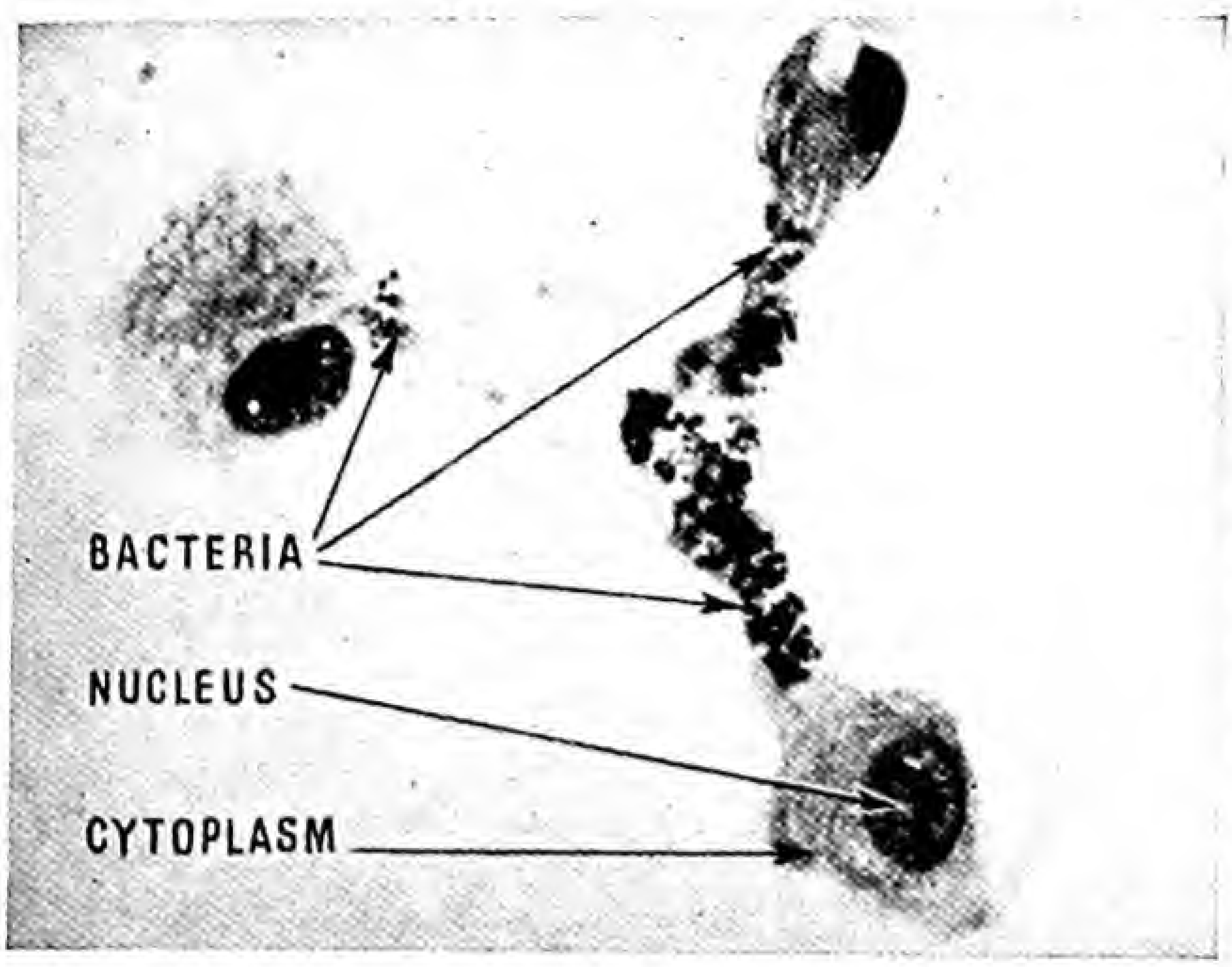
This active, artificially produced immunity protects the individual throughout life, either by altering subsequent disease so that it is only a mild form or else by giving complete protection from the disease. The introduction of this technique in 1922–23 has so changed the incidence of diphtheria among protected children that the Ministry of Health has organized a big propaganda campaign to bring home to parents and others the wisdom of this procedure.

A few figures will illustrate this point. Some 15,736 children in a group of residential schools were examined and all but 258 were protected. In following the subsequent history of these children, it was found that the incidence of diphtheria among the non-immune children was 22·5 per cent, while in the protected children it was only 0·1 per cent. We can conclude, therefore, from the experiment alone that the chance of being infected with diphtheria is 225 times greater in unprotected children than among the immunized.

Passive Immunity

Now, let us deal with *passive* immunity. When we are born we inherit an immunity to certain infections which lasts throughout life, but in addition our mothers pass on to us some antibodies from their own blood. These substances pass across the placenta, but in some animals, such as the sheep, the antibodies are passed on to the young in the colostrum (the first secretion of the mammary glands after birth).

These preformed antibodies do not last



THREE MACROPHAGES IN A TISSUE CULTURE

The bacteria are ingested by cells which have fused together for the purpose.

for long and are Nature's way of helping the young until the time when they can make their own.

This condition, which is only temporary, we call a passive immunity. We can produce this condition artificially by either injecting blood taken from a convalescent subject (as in measles) or else by immunizing an animal and then injecting the immune animal serum into a human being (as in diphtheria). This can be done prophylactically (for a child that has been exposed to disease) and so help ward off an attack of the disease, or else therapeutically, that is, to a child suffering from the disease to tide it over until it can make its own antitoxins.

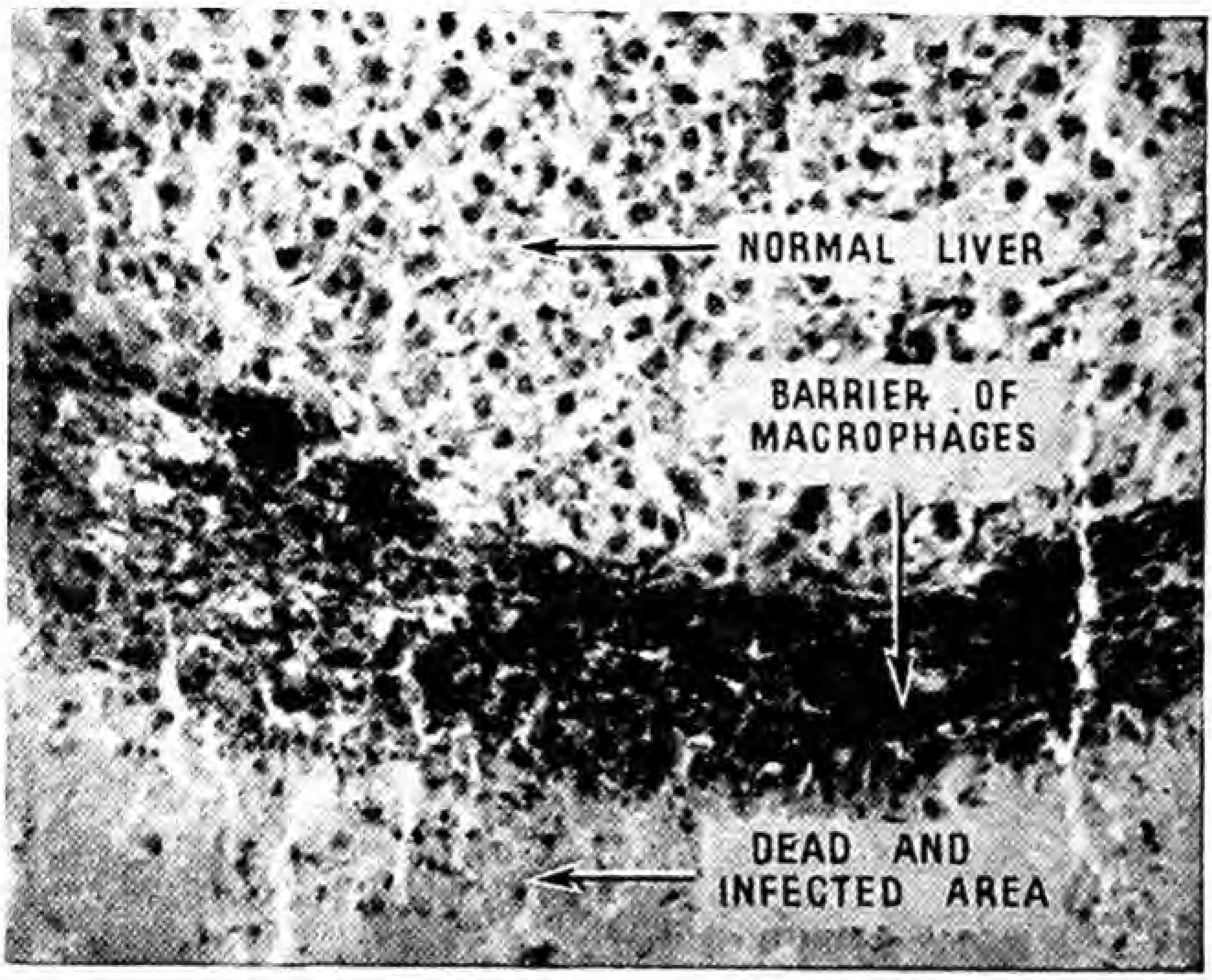
As has already been stated, diphtheria toxin is a very potent substance and if it is allowed to go on circulating in a child's blood stream the damage done increases very rapidly, so much so that whatever we do, one in every three children will die. Now, if we can diagnose the condition early and inject the antitoxin on the first day of the disease, then the mortality is reduced from thirty per cent to about one-third per cent; if antitoxin treatment is left until the third day of the disease, then the mortality rises to nearly four per cent, and on the fifth day to over twenty-one per cent.

It will be readily understood that there are many thousands of people alive today who owe their lives, not only to the doctors and nurses who treated them but also to the careful work and skill of the scientists who have made the powerful weapons with which to attack the disease or defend the patient.

So far, we have dealt only with one aspect of immunity, viz. the immunity conferred on an animal by virtue of the antibodies circulating in its blood or body fluids, and called the humoral aspect. In addition to this, there are defence mechanisms by which certain cells of the body can eat up and destroy invading organisms and foreign material (and, for that matter, dead or effete material of the animal's own tissues). This aspect we call cellular immunity. (To be strictly accurate, cellular immunity is somewhat wider than this narrow definition, but we have not space here to deal with the sub-divisions of this type of immunity.)

Defensive Cells

The body contains two types of cells which take part in this function: (*a*) the white blood cells, or leucocytes, and (*b*) macrophages. The former, which have been dealt with in Chapter VIII, are present in circulating blood to the extent of seven thousand per cubic millimetre of blood, and are continually passing by the whole of the tissues of the body. Should bacteria gain an entrance to the tissues, then these circulating leucocytes can make their way through the walls of the blood vessels at that spot and attack the invaders—this they do by throwing out part of their cytoplasm around the bacteria and



LOCALIZING INFECTION

Liver of an animal with peritonitis, showing how macrophages have set up a protective barrier between the infected area and the healthy liver.

engulfing them. This process is called phagocytosis.

Should the cells be faced by small numbers of bacteria, these are readily mopped up. Some bacteria are very virulent and may kill the phagocytes, multiply in the dead cells, escape and repeat the process. If this goes on, the animal will die. Fortunately for the animal kingdom, the vast majority of bacterial invasions are defeated, frequently without the individual being conscious of it. The pimple, boil, abscess and carbuncle are instances of infections of increasing severity which are commonly met with, but for every carbuncle we see there are many thousands of pimples which come and go with little inconvenience to the sufferer. Should an infection become established, many leucocytes will die and become the yellowish-white matter or pus, which is discharged from an abscess. The stimulus which made the leucocytes leave the blood vessels, is, we believe, a chemical one but as yet we are unaware of its exact nature.

The same stimulus, or substance, will also act on the parent cells in the bone marrow, and make them reproduce leucocytes at a much faster rate, with the result that the number of circulating leucocytes will increase considerably. When the blood of an infected person is examined, it is invariably found to contain more leucocytes than normal blood, and this increase of defence forces is one obvious means of his recovery.

The other system of phagocytic cells is more complicated and was discovered accidentally. If a colloidal dye is injected into an animal, some of it escapes in the urine and some stays behind in the body for an indefinite time, perhaps for life with certain types of dye. If the animal is killed some days after the injection and its tissues are microscopically examined, the dye is found to be stored in cells scattered throughout the body (except in nervous tissue). These cells so delineated have been called the reticulo-endothelial system, a somewhat cumbersome name. It is simpler to call them the macrophage system.

This name was given to them by Metchnikoff, a distinguished Russian scientist, who investigated the reactions of the tissue to infection and first described the role of the leucocytes (which he called microphages) and macrophages in this connexion. He used the micro- and macro- prefix to discriminate the size of these cells as well as their potency. The distribution of the macrophages throughout the body is very interesting in that they are to be found at strategic points where they can achieve their function best.

Body Fluids

The fluids of the body are threefold: (1) tissue, (2) lymph, (3) blood (in the nervous system the situation is different; here the tissue fluid and lymph are one

and the same, called cerebro-spinal fluid). Bacteria migrate in the body by means of one or more of these fluid systems. As invasion may take place by each of these routes, we should anticipate a defence system planned accordingly. We can classify the macrophage system, therefore, as: (*a*) those within the circulation, and here found to be in the liver, spleen, bone marrow and certain glands; (*b*) in the sinuses of lymph glands through which all lymph must flow sooner or later; (*c*) in tissue fluid spaces throughout the body.

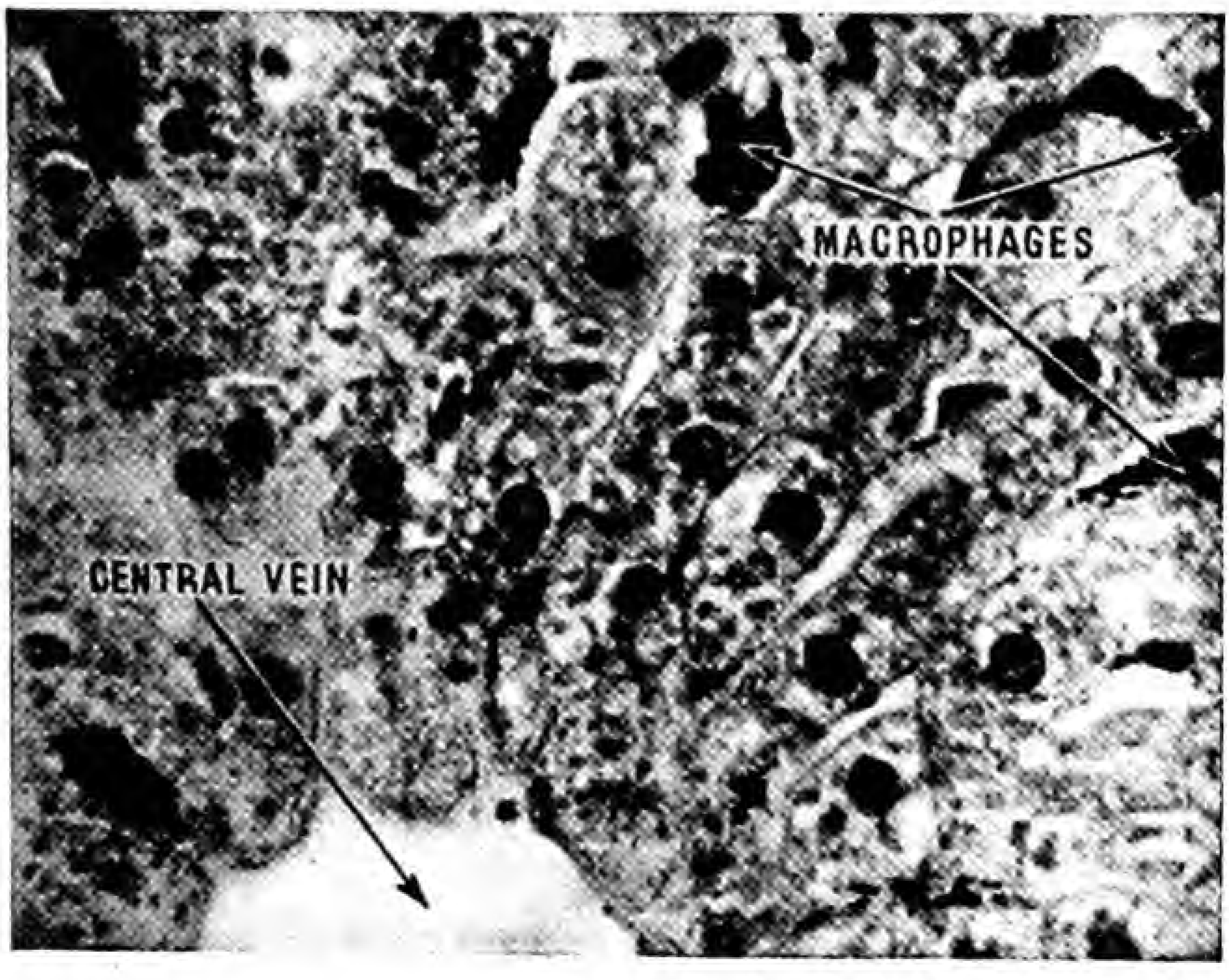
The liver furnishes a good example of strategic distribution. The lumen of the intestines is teeming with bacteria and the blood from there must go through the liver before entering the systemic circulation.

Suspended from the walls of the liver vessels are macrophages which sway to and fro in the stream of blood flowing past them, and any foreign body floating by is rapidly seized and dealt with. Similarly, in the lymph gland, macrophages attached to the walls of the sinuses can ingest any bacteria or other matter that drains from the tissues through a particular gland.

Nature is always economical and these cells illustrate this point. Infection is an eventuality that may seldom happen, so we find that many other functions are performed by the macrophages. For instance, they are general scavengers and remove dead or unwanted tissue. Those in the spleen are kept quite busy removing and breaking down worn-out blood cells. The macrophages in the liver will remove certain vitamins from the blood and pass them on to the liver cells for storage, or again those in the bone marrow remove iron from the blood and pass it on to other cells for the manufacture of haemoglobin, the oxygen-carrying pigment of the red blood cells.

To return to the question of infection. The course of events is as follows: when invasion occurs, the relatively few local macrophages will do their best, but are soon reinforced by leucocytes which, as we have said, leave the blood stream nearby for this purpose. Many more leucocytes will be brought hither by the blood as the bone marrow gets busier. After three days, the same substance which stimulated the marrow to produce more leucocytes, has had time to stir up the macrophage system in general (this is indicated by the swelling of the lymph glands draining the infected area).

These cells multiply and migrate to the site of infection. When they reach there, being more powerful cells, they take command of the situation and as well as destroying the invading forces they set up a barrier, walling off the infected tissue from the surrounding healthy tissue, and so localize the infection. Later, they will eat up the dead and dying tissue and make



WORK OF MACROPHAGES

Liver of animal with macrophages distended with Indian ink. The ink was injected into the blood stream during life and removed therefrom by the macrophages.

PENICILLIN RESEARCH WORKER

Dr. Chain, a biochemist and a refugee from Nazi Germany, was one of the pioneers in the work on penicillin in Britain. He is seen with his assistant adjusting a reflex condenser over a flask in part of the technique in the isolation of penicillin.

way for the reparative processes, which we call healing.

In addition to these actions, we believe they play a part in the manufacture of antibodies. We know now that the antibodies discussed earlier in this chapter are manufactured in the lymph glands, and it is highly probable that the cells which destroy the antigens, in doing so, learn something of the chemical structure of those bodies and so are enabled to build another substance—the antibody—to combat it (as a locksmith may produce a key to fit a lock, if he can see inside it to investigate the wards).

The advent of the knowledge that bacteria may produce disease, stimulated research workers to find an antiseptic which could be injected into the body and so kill the bacteria without at the same time injuring the animal or human being. This search has been a long and sometimes misguided one. Misguided because in general this viewpoint is anti-biological, in that substances which are poisonous for one form of life are frequently, although not invariably, inimical to all forms of life. The first success in this field is to be attributed to Ehrlich, a German scientist, who discovered salvarsan (or 606, which is the number on the list of substances he synthesized or tried) an organic arsenic compound used with great success in the treatment of syphilis.

It is through the agency of the macrophage system that salvarsan becomes effective. We believe that the macrophages ingest the compound and break it down, thus liberating arsenic in a form that is lethal to spirochaetes in their locality. During the past twelve years we have seen remarkable advances in this form of treatment. The sulphonamides were introduced in 1935 and soon radically changed the course of certain bacterial diseases; for instance, puerperal fever, which was a killing disease attendant on childbirth, lost its terrors and came under control. Some bacterial diseases are not affected by the sulphonamides. Experience and research have told us which of the sulphonamides are effective against particular bacterial diseases and also how these synthetic chemical substances act. They are not antiseptic, by any means, and if the doctor wishes to inject them into the body he has to be sure that they are sterilized first.

If they are not antiseptics, how then do they act? The answer to this is as follows.

Some bacteria need to feed on a chemical substance of a similar nature to sulphonamides in order to grow, and if the concentration of sulphonamides in the body fluids is sufficiently high the bacteria are unable to utilize this substance and so are unable to reproduce. The number of infecting bacteria in the body is therefore limited, and the phagocytes, previously discussed, are readily able to cope with the invaders. Substances of this kind are called anti-biotics.

One significant and fundamental property of living matter is the power to adapt itself to its environment ; if adaptation is not achieved death is inevitable, and so it is with bacteria, and herein lies a danger of indiscriminate use of sulphonamides. Some bacteria are able to adapt themselves to an environment containing sulphonamide and become what is called sulphonamide-resistant strains. Should a human being thus produce a sulphonamide-resistant strain of bacteria, the development of the disease cannot be checked by the use of this drug. It should be widely known, therefore, that the indiscriminate use of the sulphonamides may be a source of danger not only to the individual taking it but also to the community.

Another great triumph of recent years is the discovery and use of penicillin in the fight against disease. Sir Alexander Fleming noticed that a fungus prevented the growth of certain pathogenic bacteria. He identified the particular fungus as *Penicillium notatum*; he further showed that the fungus produced a substance which was of itself able to inhibit the growth of bacteria. Sir Howard Florey and his colleagues followed this up and succeeded in isolating and purifying this substance so that it could be injected into human beings without producing any harmful effects.

This later work was done largely during the war years and, fortunately, was sufficiently far advanced to be used on wounded soldiers with spectacular success. It is too early yet accurately to assess the ultimate value of penicillin in the treatment of the many and varied bacterial diseases, but it is already certain that a number of diseases otherwise fatal can be cured by the use of penicillin.

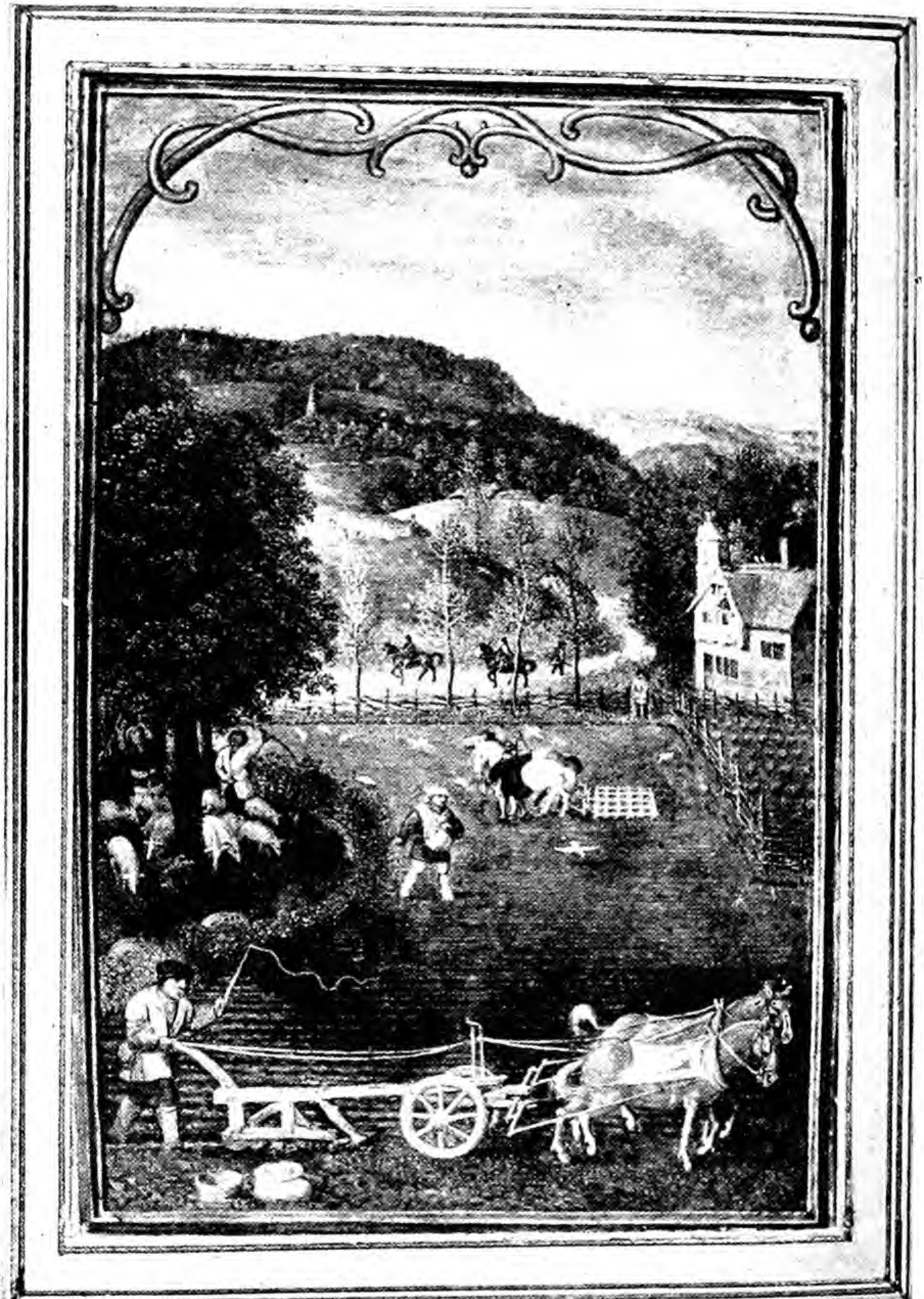
Research workers in many lands are searching for more of these chemotherapeutic substances so that cures may be found for diseases which as yet have defied us. There are signs that a substance will before long be found to treat the dreaded disease of tuberculosis.

We have every reason to be grateful to these patient and often brave men, who, since Leeuwenhoek gave them eyes, have investigated the world of bacteria. They have learned much about our unseen foes, and discovered many fine weapons for our defence.

Test Yourself

1. What are antibodies and where are they formed ?
2. What is meant by " acquired immunity " ?
3. In what ways are bacteria useful to man ?
4. What may be the consequences of drinking impure water ?
5. Describe some of the functions of the macrophage system.

Answers will be found at the end of the book.



AGRICULTURE IN THE SIXTEENTH CENTURY

Domestication of animals and cultivation of the land are among the oldest occupations of man. The picture, which is reproduced from an old Flemish print, shows the type of horse-drawn plough used in the early sixteenth century. A young orchard is seen on the right.

CHAPTER XVII

MAN AND NATURE

FOR all living things, life is a constant struggle. A struggle for food, for light, for air, a struggle against enemies, a struggle for existence itself. Every living thing has its enemies, not necessarily other animals or plants, but anything which makes life difficult or impossible.

Man's enemies are legion. The very fact that his mode of life has become so complicated, has increased the natural forces ranged against him. But his physique and superior intellect have given him the ability to control these forces to a great extent and to bend them to his own ends.

In many directions, his achievements have been wonderful. Scientific cultivation has improved the food value of many plants, to the benefit of man and other animals. Selective cross-breeding has produced herds of healthy animals. Man has learnt how to utilize even artifical combinations of chemical elements for clothes and adornment, and, more latterly, his war on the minute organisms which cause disease among men and animals, has produced some marvellous results.

Unfortunately, many mistakes have also been made, sometimes through ignorance, sometimes through greed, but largely through not looking sufficiently far ahead. Slowly, man is beginning to realize that things which are taken away must be replaced. But he has still much to learn of the devious ways of nature. He needs to study far more closely the influence of plants and animals upon one another, and the possibilities arising from any interference with natural phenomena. Above all, he needs to be very careful how he upsets the balance of nature.

Originally man, like most animals, took food as the wilds presented it to him. If times were good he fared well; if bad, then badly. A day came when instead of relying solely on wild plants for food, he began to grow them for himself. Then he learned to domesticate animals, and some of them, the cow, the sheep, and the goat became permanent, or semi-permanent, sources of food. This was during man's nomadic stage, pictured for us in the Bible in Abraham's time, and still surviving to some extent in the East and Middle East. Gradually, communities settled down, homes were built and civilization, as we know it, began.

Improving on Nature

Since that time, man has set himself to produce better and better cattle and sheep (from *his* point of view) and better and better wheat, maize and other cereals, also fruits and vegetables, and, further, he has learnt how to keep food over a period of scarcity from one harvest to another.

As regards domestic animals, he protects them from wild animals and to some extent from the weather. He does not leave them to fend for themselves entirely. The ewes of mountain sheep are brought down to the more sheltered and fertile valleys before the lambing season. Cattle are fed in the winter and early spring months from stores, or, for example, hay collected, perhaps, the previous year, or specially grown roots and cabbage, or from the residue of vegetable seeds, etc., used in the making of oils (linseed, peanut, palm kernel). In all this, man is interfering with the course of nature and he interferes so that he may have more food to feed himself and his livestock.

Then, he breeds animals especially for definite qualities. If he wants quantity of milk he produces the Friesian black and white cattle. If he prefers quality, then the Guernsey or Jersey. And, once having produced his strain, he tries to keep it pure. This is distinctly against nature. Further, as he wants milk in the winter as well as the spring, he encourages his cows to produce "back-end" calves—calves born in the autumn.

It is more normal for them to produce calves in the spring, with the result that

there is a surplus of milk in the spring or summer and a deficit in the winter. Man interferes again. Breeding for milk production for *man* is in itself an interference. In its natural state, the cow produces just enough and no more than enough for the calf, a very few hundred gallons. Man encourages the cow, by feeding and careful selection in breeding, to produce on the average seven hundred gallons a year, and the best milkers double or even treble that amount. If that quantity of milk were fed to the calf, it would die!

Now, the production of large amounts of milk is an inherited character and is handed on, oddly enough, via the bull. Man is interfering again. He wants, all over the civilized world, to raise the standard of milk production in cows. One bull can father many more calves if artificial insemination is adopted, and it is now being widely used.

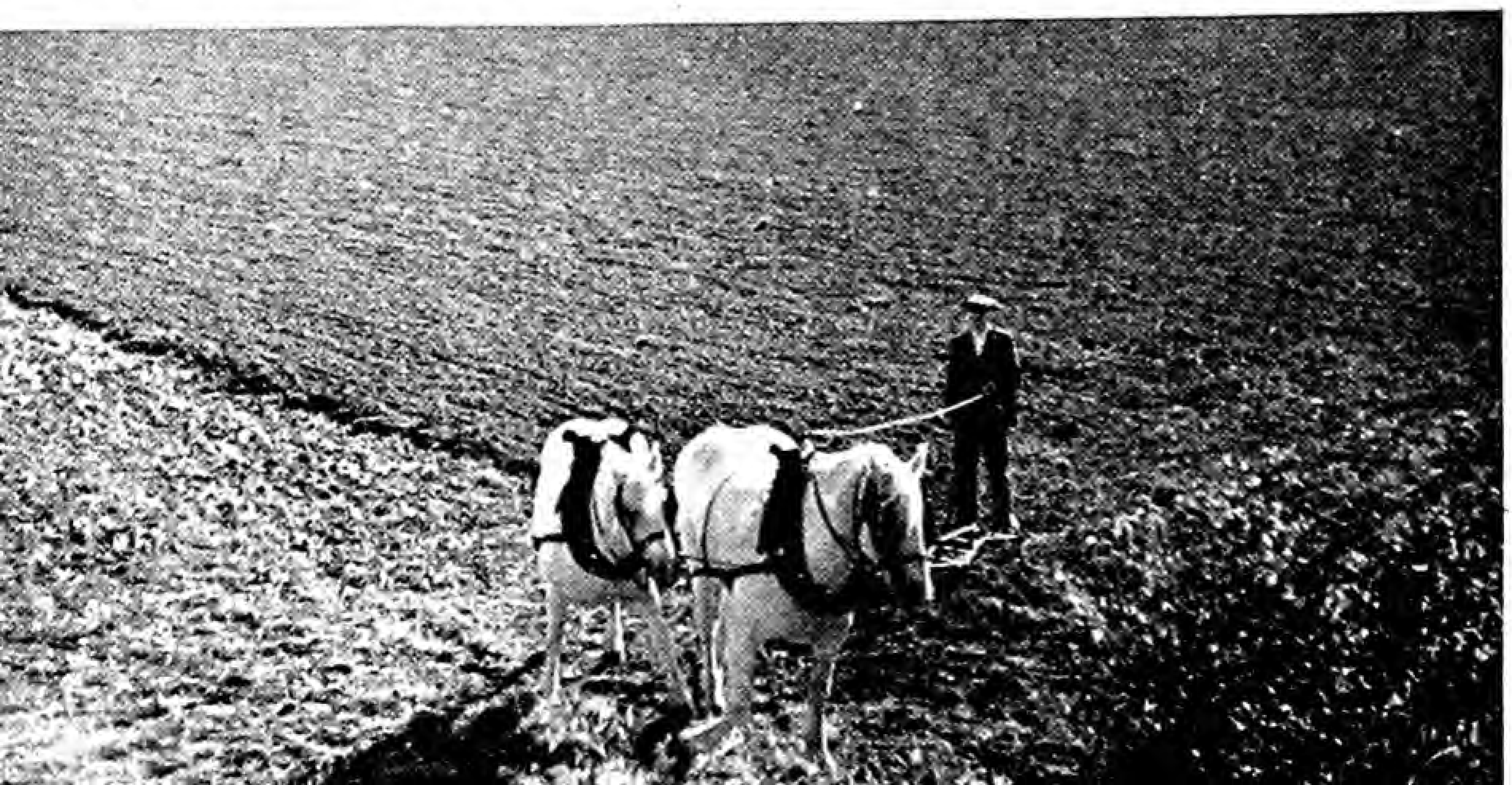
Just the same occurs in plant breeding. Wheat has been one of man's chief articles of diet from prehistoric days and there are evidences from earliest times of his efforts to improve the crop, not only from the point of view of greater yield but also of better quality of grain. More recently, he has begun to cultivate it for particular qualities such as ability to stand up to heavy rain, or resistance to infection with rust combined with heavy yield. In Canada, they are cultivating wheats to increase the yield of vitamin B1. Already they have produced wheats to crop quickly, so that they ripen in the short but intense summers of northern Canada.

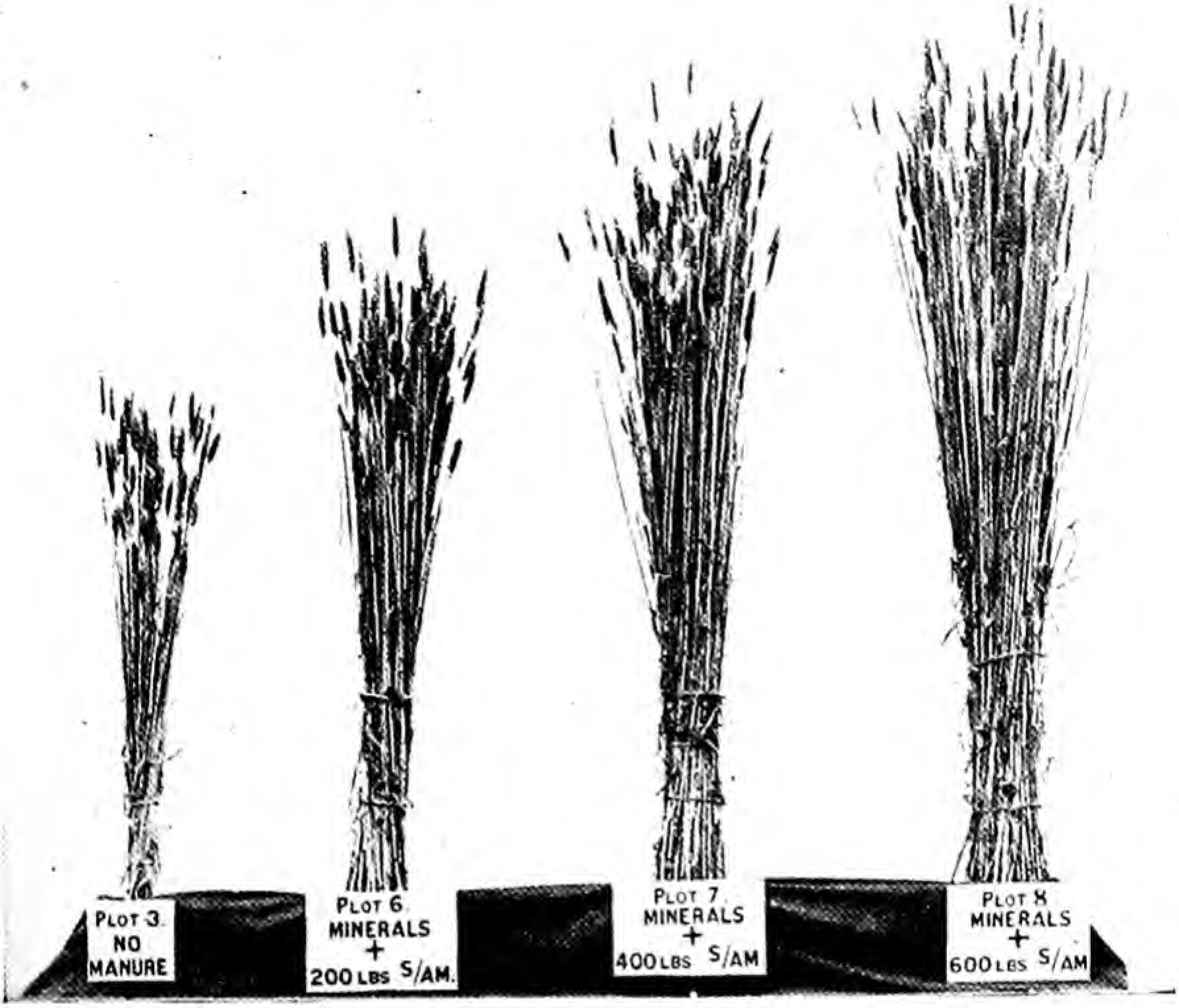
And the same is true of maize; the Rose-Innes research station has bred a maize which will ripen in the queer varieties of weather which go to make the English summer. Similar principles have influenced fruit and vegetable growing; quantity of yield, appeal to the eye and palate, time of maturity and now, more recently, vitamin values. Always man's aim has been to encourage nature to produce something more valuable and attractive to himself. In doing this, he has sometimes landed himself in grave difficulties.

In recent years, man has turned his attention and his scientific knowledge to the control of pests by biological means. Animals, fungi, bacteria and viruses find man's food (both animal and vegetable) to their taste. If man is careless in the growth, storing or scattering of his food, these pests multiply. Rats infest the wheat stacks and the granaries. Rabbits thrive around his farms. Slugs, snails and caterpillars devastate his lettuces, cabbages and so forth. Plant lice attack all his succulent fruit bushes, and, worse, carry viruses which destroy their

THE GOOD EARTH

Successful crops depend largely upon the proper preparation of the ground. After ploughing, a harrow is used to break down the soil into fine particles and make a good seed-bed.





EXPERIMENTS IN WHEAT CULTURE

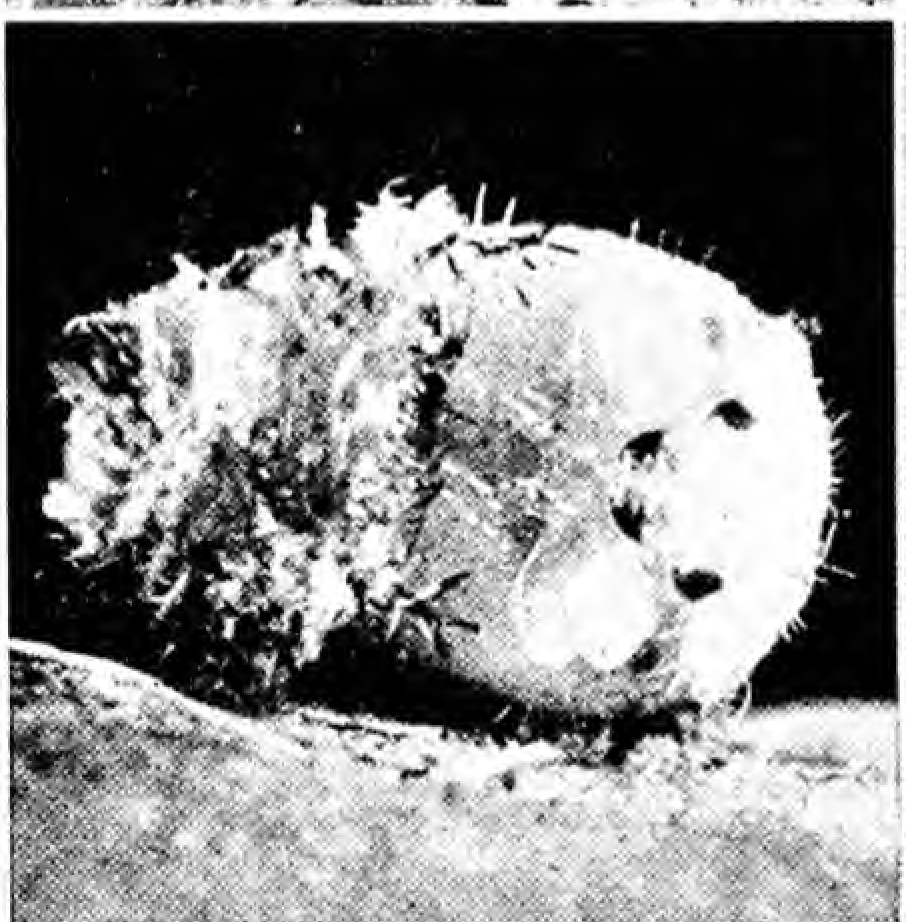
Samples of wheat grown at the Rothamsted Experimental Station, Hertfordshire, showing the effect on plant growth of adding artificial fertilizers, including sulphate of ammonia, in increasing quantities, to the soil. Plot No. 3 has received no manure for a century.

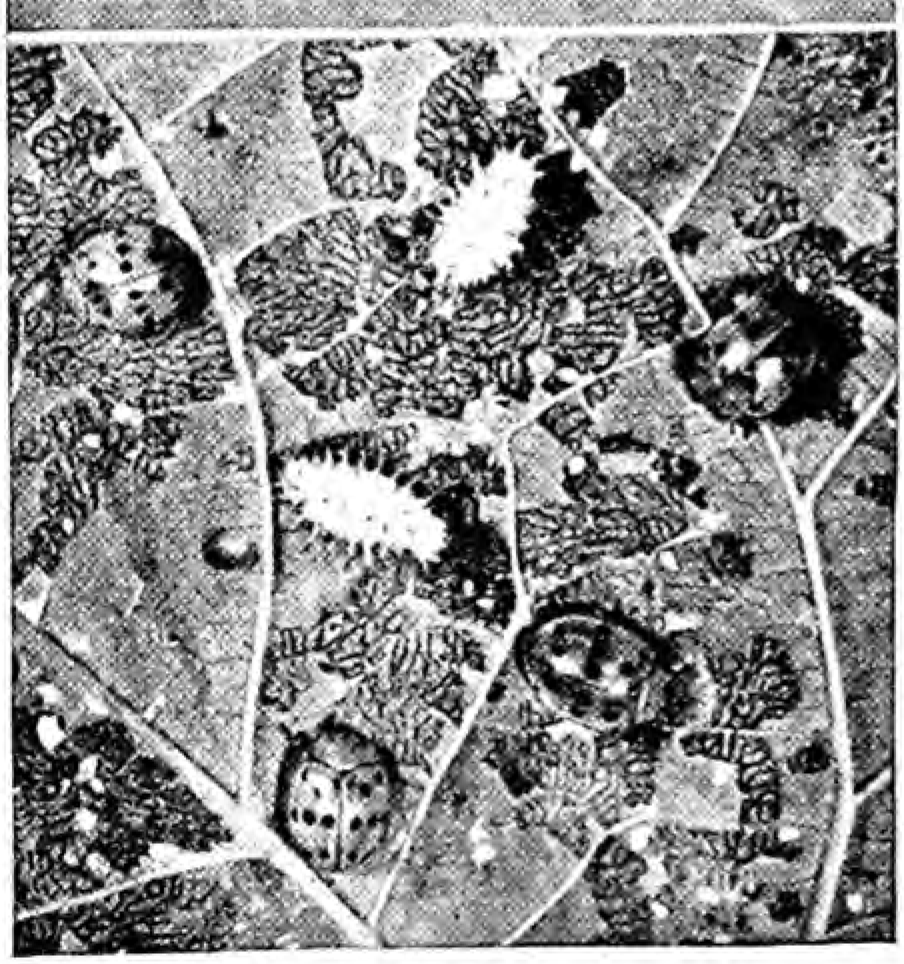
power of yielding fruit. Microbes grow in milk and sour it or transmit disease.

In producing fine vegetables and fruits for himself, man has given the pests their chance, and they take it. Now, he is faced with the necessity of getting rid of the pests, but so far he is only in the process of learning how to control them. One of the chief methods of destroying insect pests is to spray the plants on which they feed with poisons such as derris, pyrethrum or nicotine solutions. More recent remedies are DDT and Gammexane. Slugs and snails can be killed by metaldehyde. Fungoid blights which thrive on fruit and vegetables are treated with tar-oil and lime-sulphur sprays and with Bordeaux mixture.

Agriculture and horticulture present one long struggle against pests. If the potato blight gets a hold, the potato crop will be lost. The flea beetle will ruin the turnips; the caterpillar the cabbage crop; and sundry moths and other insects the apples. It is an endless fight. Now, in all this, man is pitting his hand against nature and he has to ask himself whether his methods of breeding animals and plants for particular purposes, or, indeed, any of his agricultural methods, may not bring worse troubles in their train.

It has to be admitted that often he has made disastrous mistakes in the past and still is doing so. A typical example can be seen in northern Nigeria. The native, to grow his yams, which need a highly nutritious soil, hacks down a patch of the jungle





FARMER'S PEST

The Mexican bean beetle is one of the farmer's most destructive pests. Both adults and larvae feed on the bean leaf and will strip a plant of its foliage in a short time. The picture in the top left shows the larvae hatching from the egg and already setting to work devouring the bean leaf on which they have been hatched. On the right (top) is a magnified picture of the Mexican bean beetle larva. Its back is covered with tree-like spines. The next picture (on left) shows the insect shedding the larva skin. On the right is the adult beetle and (below) adults and larvae feeding on a bean leaf. Fortunately, means of destroying such pests are available today.

and plants his yams in the mass of detritus of leaves below. In doing so he ruins valuable timber. Also his yams soon exhaust the soil and the native moves on to a new patch. The jungle never properly remakes itself; what soil there is, is washed away by the heavy rains, and the desert advances.

We can, perhaps, forgive the native mind its lack of knowledge and prescience. But civilized man has done, and is still doing, much the same. Particularly is this in evidence in the prairies of the United States and Canada. Man has ploughed up grasslands, sown them with wheat and used artificial fertilizers, instead of replacing the humus (decaying and decayed vegetable fibres which bind the soil together). Rain has washed away this soil into the rivers, whence it has been carried to the sea; and this process has created the notorious dust bowls of the prairie provinces and states.

Apart from this, his ploughing has often resulted in the same thing. If he ploughs across the contours of the land, the natural drainage carries away the soil into the rivers and it is lost. To prevent this, contour ploughing is essential and is widely preached though not always adopted. Similarly, the destruction of trees has left the soil open to the eroding effects of rain, and again the soil has been washed away. The Tennessee valley is a grave example of this. Further, the denuding of tracts of the country of their forests has altered the rainfall and has turned an area of considerable precipitation of rain into one of drought. Conservation of the soil and the maintenance of forest belts to encourage precipitation of rain and to act as windbreaks, are essential in a sound agriculture.

In animal breeding, man, in his desire for highly specialized types, has run into difficulties. If you specialize hens for laying eggs, they lose their instincts for sitting and bringing up of a brood of chickens. That entails the use of incubators and artificial brooders. Now, however efficient these machines are, the loss of potential chicken life is very much greater than if the eggs are hatched under broody and maternally-minded hens.

The breeding of cows for high milk production puts such a strain on them that

COLORADO BEETLE
Pest, common in North and South America, which feeds on the potato plant. Its depredations are so serious that in an endeavour to keep it from spreading in Britain, any person finding one is required to notify the authorities immediately.

they easily succumb to bovine tuberculosis. In man's desire to reap a quick return, he imposes frequent pregnancies on the cow and this lowers resistance to tuberculosis and he defeats his own ends. The evolution of a specialized animal often has entailed inbreeding, or mating of closely related animals.

Now, carefully controlled inbreeding, with culling of animals that show physical weaknesses, may produce a robust stock. For example, the Wistar Institute Laboratory rat, produced by brother-sister mating, has resulted in a sturdy standardized stock. But careless inbreeding often, indeed usually, enables unsatisfactory characteristics to show themselves. Inbred stocks often show marked susceptibility to disease. Much more scientific knowledge than is at the disposal of, or is used by the farmer, is essential to successful inbreeding.

Upsetting the Balance

The introduction of Old-World species of animals and plants into new countries has often worked havoc. Man upsets the balance of nature and pays the price. The best examples of this are the introduction of the rabbit and the cactus into Australia. The natural enemies of the rabbit were absent in Australia, so their multiplication was unrestricted and has entailed the making of hundreds of miles of rabbit-proof fencing in that country to stop the depredations of these destructive animals.

Sometimes, the importation of the natural enemies has proved of avail, but it needs the greatest care and foresight. The classical example is the introduction of ladybirds into California to defeat the activities of the scale insect, which was ruining the crops of oranges and lemons. In this case it worked wonders, but there is always the danger that the introduced animal may turn its attentions in directions other than the useful one.

Californian Fig Problem

Insects which keep the cactus within bounds in the Argentine have been introduced into Australia to check the rampant growth of that plant, and so far with apparent success. Another example of the use, but not of the danger, of importing an animal is seen in the growing of figs in California. Figs from Greece grew well in California but never made satisfactory fruit. It was discovered that the attentions of a particular kind of wasp are necessary for the fertilization of the flowers within the fig. These wasps were imported and the Californian fig trees then proceeded to set fruit. As there is a highly specialized relation between the figs and that species of wasp, there is little danger that those animals will ruin other crops.

As mentioned above, the breeding of organisms specialized for a particular purpose opens the door to disease. So do many of the methods of agriculture. Naturally, the husbandman plants many of the same kind of plant close together. He gathers his apples into an orchard and his fruit bushes into a fruit farm. Consequently, fungus spores have much less distance to travel from plant to plant than they would in natural conditions, and so fewer "fall by the way" on unfertile soil.

The aphis (plant louse) carries a virus disease which affects strawberries. Wind can carry aphides a mile—so that you cannot rear virus-free strawberries within a mile of tainted stock. How much easier, therefore, it is for an aphis

COLORADO BEETLE LARVA

Close-up of the larva showing body distended after eating large quantities of potato plant leaves.

to carry the disease to a plant eighteen inches away.

The relationship between agriculture, game preservation and disease can be illustrated by sleeping sickness and by nagana, a closely related disease in domestic animals in Africa. These diseases are carried by the tsetse fly. Life becomes impossible for men, horses, mules and donkeys where the tsetse fly abounds. Now, scrub bush harbours this insect. To get rid of it, you destroy the bush. But this opens the way to soil erosion, so the remedy is almost as bad as the disease. Moreover, nagana is not fatal to the native antelope and probably the native buffalo, though a carrier, is not killed by it. Game preservation, therefore, encourages nagana.

It would appear that the best way of making the present haunts of the tsetse fly habitable to man and his domestic beasts is to trap it, or possibly to kill it with D.D.T. or Gammexane. Some have advocated the destruction of the natural reservoirs of nagana, that is, the antelope and the buffalo, but, there, sentiment interferes. It must be confessed that the destruction of natural fauna, even though they are potential sources of disease, is repugnant to most people to-day.

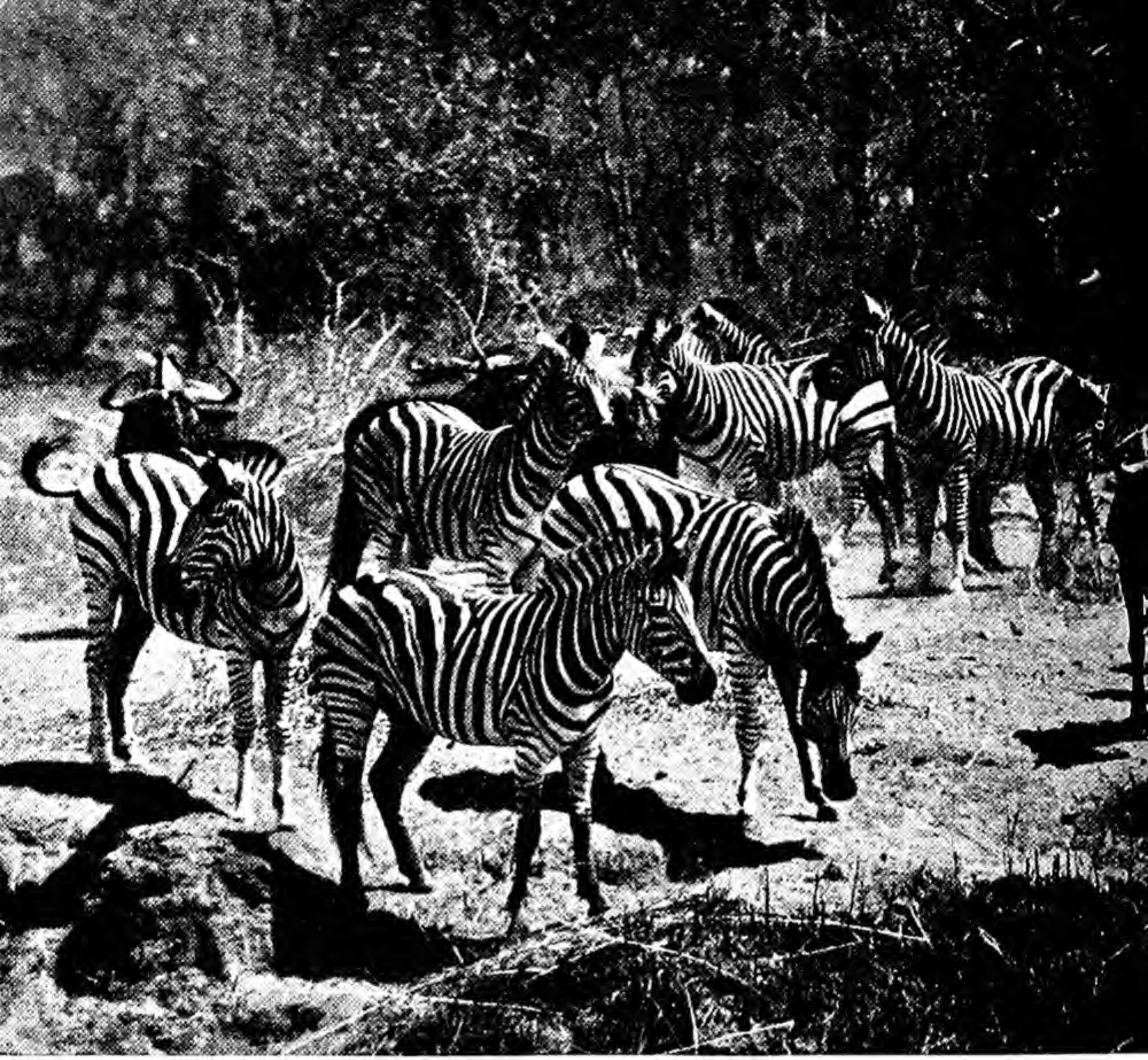
Man the Destroyer

Man has often been called the arch destroyer. From his earliest days, he has hunted and destroyed animals. At first, he was largely dependent on them both for food and for clothing. Later, he hunted animals for sport or pleasure. Many species of plants, as well as animals, were wiped out from some parts of the world, while others were destroyed altogether.

SWARM OF LOCUSTS

Plague of man since ancient days. Locusts are migratory insects which swarm in dense clouds. When they descend to breed, they strip all surrounding vegetation. Below is a close-up of this destructive insect.

Quite a long list could be compiled of animals which have been blotted out of existence during the last two centuries alone. Steller's sea-cow, a creature not unlike a huge porpoise, was hunted for its valuable oil and exterminated within twenty-seven years of its discovery. The quagga, a kind of half-striped zebra, fell a prey to the collector's mania. Among birds, the dodo is a well-known example; and the moa of New Zealand, an ostrich-like bird,



disappeared about the middle of the nineteenth century.

Even the rivers and oceans have not been safe from man's rapacity. Here again, he has helped himself so freely that some areas of the sea have become completely fished out. The disastrous results of fishing out, or overkilling, are well illustrated by the position in the whale industry to-day. The whale, of course, is no fish, but a mammal which has taken to the sea. So grave have been the depredations of man in search of whalebone, blubber oil and, now, meat (whale steaks are edible) that the Arctic seas are almost denuded of whales. As is well known, whaling is carried on chiefly in the Antarctic regions, and the whaling stations are in South Georgia and the Falkland Islands.

The problem of preventing further depletion of the whales is made more difficult by the fact that whales are mammals. This means that the female should be protected during pregnancy and lactation, if not throughout life, but how the harpooner can hope to distinguish females at sight presents a problem. This difficulty has not yet been solved. And if we fish out the whales, farewell to an important source of oil for the manufacture of margarine and other valuable by-products.

For centuries, man continued on his path of destruction without giving a thought to replacing or renewing the riches of which he availed himself so lavishly. But at last, he began to awake to the fact that the bounties of nature are not inexhaustible and that if he were not more provident, supplies would eventually dry up at the source.

Laws were introduced, known as game laws, limiting or prohibiting the destruction of certain animals and birds. In the United States and Canada (and in other parts of

WILD LIFE PRESERVATION

In order to preserve wild life, both plant and animal, from extermination, large areas have been set aside in many parts of the world where the natural inhabitants may live unmolested. The photograph shows wildebeeste and zebras in the famous Kruger National Park, South Africa.

the world), large areas of land have been enclosed as national parks, where wild animals live in their natural surroundings, undisturbed. Bird sanctuaries and zoos are common in most civilized countries today.

Steps have also been taken to safeguard the world's fishing grounds by such expedients as prohibiting the use of nets with too small mesh and by suspending fishing for certain species during the breeding season. Complete control of the danger of depletion of fishing grounds will only be possible when we know much more about the food of fishes (the plankton and nekton), about the oceanic currents and the migration of fish in search of their food. Much has been done to elucidate these problems: much remains to be done. And there is the possibility of extending the use of fish hatcheries, where the eggs are artificially fertilized and the young fish reared.

All this goes to show the futility of the short view against the long view. The natives of Nigeria, taking the short view, ruin the jungle by cultivating their yams in its detritus after they have cut down the trees, and allow the desert to overwhelm the jungle. In the prairie provinces of the U.S.A., the farmer has cashed in on the stored fertility of the grasslands and left them a dust-bowl. On land, many interesting and valuable animals have been hunted to extinction. In the seas, there is danger, by over-exploitation of its riches, without heed to the conservation of their sources, of rendering them useless as a supply of excellent food. Man, unless he takes the long view, by soil conservation, by guarding against extinction of useful animals and by replenishing the seas, literally digs his grave with his teeth. Nature never forgives. Work with her and all is well, but work against her and destruction will almost certainly follow.

Securing Food Supplies

As we suggested earlier in this chapter, man's chief end in bending nature to his will has been to obtain more, better and more constant sources of food. And having got food, he wishes to store it against a time of scarcity. He wants to make food keep. Foods which are the seeds of plants will keep almost indefinitely if stored dry and protected from animals. After all, the plant produces seeds in order to maintain life through winter or through periods of drought. Man makes use of that fact.

With other foods, preservation is not so easy. The body-building foods (meat, milk, fish and eggs) and fruits and vegetables, cannot be kept long without decomposition at the hands of microbes. Man defeats the activities of these microbes in many ways. He may dry the meat and fish (and more

ARTIFICIAL BREEDING OF FISH

The top picture shows fish being fed in a trout fishery in Somerset. Male and female fish are kept in separate ponds until maturity, when they are removed to the hatchery for artificial breeding. Each hen fish is held over a dish and gently squeezed until she exudes her eggs. Later, the milt from a male is squeezed over them (see below). The ova are kept in running water and the young hatch out in about seven weeks.

recently milk and eggs). Microbes cannot live in the absence of water. Or he may salt or otherwise cure the meat or fish. Microbes do not flourish in strong salt solution; and the smoke which is used in curing bacon and herrings contains an antiseptic. So decomposition is delayed.

A further method, used to preserve fruits, is to cook them with sugar, as in jam making. Microbes cannot live in strong sugar solution. Then he may kill the microbes by sterilization with heat, and seal the food away from fresh contamination in lacquered tin-sheet containers. The canning industry has grown to huge dimensions in this century and is applied to meats, fish, milk, fruit and vegetables. A further method of preserving food is to freeze it rapidly and keep it in cold storage.

Now, in storing foods man reaps enormous advantages, but he also at the same time loses something. There is no doubt that fresh foods in the long run are better for health than preserved foods. During drying, one of the vitamins (C) is destroyed. Canning also destroys this vitamin, though the loss has been grossly exaggerated. Canned fruit may have more vitamin C than fruit bought in the open market and stewed at home. In canned herrings, there is a loss of vitamins A and D. Until experiments made during the Second World War showed the way, dried vegetables were almost devoid of vitamin C. Canning destroys the vitamin B1 in meats and fish.

The milling of cereals provides another illustration. Wheat will store almost indefinitely, particularly if sterilized and kept dry. Wholemeal flour will not keep so well. The fat in it goes rancid. Moreover, mites and weevils revel in it. White flour, on the other hand, will keep for a much longer period, but in milling white flour the miller gets rid of much—though not all—of the vitamins B1, riboflavine and nicotinic acid.

So long as man knows the results of his processes of conserving food, he may guard against the disadvantages involved. The danger is ignorance. Canned foods are not dangerous, but they may be less nutritious because they have lost one or other of the properties of fresh foods. Replace these properties from other sources, and canned foods are very valuable adjuncts to our commissariat.

Little of the food we eat today in its present form bears any resemblance to what it would have been without man's interference. The fact is, man's whole life depends on his interfering with nature.

It is with the far-reaching consequences of his interference that he must concern himself, if his efforts are not to defeat their own ends and lead ultimately to disaster.

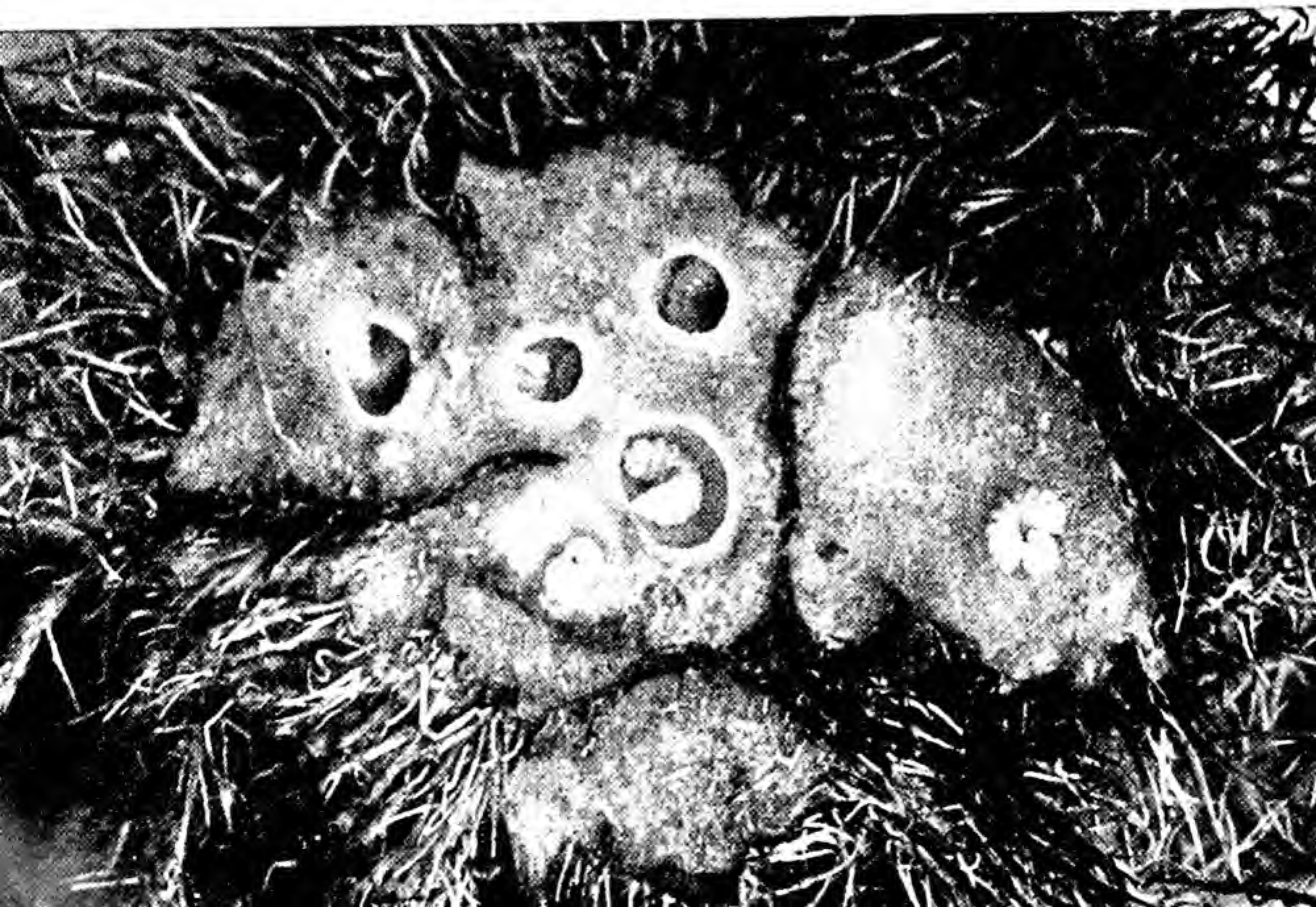
Test Yourself

1. How can domestic animals be protected from their enemies?
2. State some of the methods of control of insects that attack crops.
3. How can bad forestry affect the suitability of land for agriculture?
4. What are some of the disadvantages of breeding animals or plants for a particular quality?
5. Why was the introduction of rabbits into Australia so disastrous?
6. How many ways of conserving wild life do you know?
7. Can rivers, lakes and oceans be made more productive?
8. Would you say that by and large man's interference with nature has been beneficial or otherwise?

Answers will be found at the end of the book.

BEDEGUAR GALL ON ROSE STALK

This type of gall is produced by the gall-fly Rhodites rosea (*inset*) *and is found only on plants of the rose family. It is reddish in colour and looks like a mass of fine threads or tendrils. In the lower picture it is seen in section and shows the cells with larvae inside.*



CHAPTER XVIII

UNSOLVED PROBLEMS AND RIDDLES

THE poet Pope in his *Essay on Man*, speaks of "The Eel of Science"—of catching the eel of science by the tail. Now to catch an eel by the tail is a difficult task. Yet, it seems, we must now attempt it. The eel is extremely slippery.

The reader will by now have acquired many facts, and these facts he will have found arranged, or partly arranged, on a scaffolding of theory. He will have read of evolution and of the means by which evolution has been supposed to take place. The aim of this chapter is to present yet other groups of facts in the form of animal life-histories that do not easily fit into any of the theories. Let us begin with an account of some of the gall-flies.

The many kinds of galls which occur on plants are caused by parasites, sometimes by fungi, sometimes by insects. The presence of these parasites—the mycelium of a fungus, or the egg or larva of an insect—in the growing tissue of the tree causes a change in the adjacent cell-substance of the plant. It is affected by an enzyme, and instead of the plant growing normally, it swells rapidly into tissues and organs of new and unusual shapes, yet in each case characteristic of the parasite which has attacked the plant. This new abnormal structure, the gall, becomes both the home of the parasite—its true environment—and its food supply. The parasite avails itself of this rich food-tissue and thus continues to grow.

In some cases, however, the host plant is able to build a wall of hypertrophied tissue between that part infected by the parasite and its main body. In this way a conflict of vitalities ensues. Chance, or perhaps purpose, will favour the host or parasite as circumstances decree. The wall built against the parasite contains no nourishment that can be used by the parasite, since it is made chiefly of corky cells which cannot be penetrated or destroyed.

Specially noticeable and peculiar are the galls caused by insects. The grub when it emerges from the egg finds a world well suited to its liking, and as a rule lives at the expense of the plant. There are occasions, however, as will be seen later, when the gall-producing insect actually makes a contribution towards the welfare of the host plant.

Gall-Making Insects

The insects most usual in making galls are mites, gnats and wasps. Some thread-worms, Nematodes, also cause galls. Sometimes the galls are solid, like oak-apples. When this type of gall is formed, the insect pierces the plant tissue and lays an egg in the wound. Either the epidermis of the chosen spot is injured or the egg is inserted into deeper-lying tissues. In both cases local protective action is taken by the plant, and it is not until the grub emerges that the active cell-division of the host plant takes place. It is interesting to note how the growth of the tissue of the host plant seems to *obey* the behest of the parasite. The cells which are nearest to the young grub are juicy and thin-walled. Just the sort for a young grub to appreciate. They start to develop with rapidity as soon as the egg has been laid, and the larva when it is hatched immediately devours the juicy substance; and, most wonderful to tell, the cells which are devoured are almost at once replaced. A leaf eaten by a caterpillar does not replace its tissue, but the substance in a gall is more obliging, so obliging indeed that as though aware of the needs of the parasite, this substance will be faithfully replaced until the time when the grub is full fed and ready for its metamorphosis. The larva traverses the inner chamber of the gall, eating its way through and around as it continues its wanderings. By the time it

AFTER EMERGENCE

Marble gall-wasp resting on the gall from which it has just made its escape. Note the neat round hole through which it has eaten its way out of the gall-nut.

has returned to the place where it started, new cells have been formed to nourish it.

How different are the cells which grow on the outside of the gall. They form a skin or bark and afford a protection. Try to cut an oak-apple, and you will see how hard this protecting bark can be. Whatever the "intention," the plant has in fact built a fortress for its parasite which protects the gall from drying up, and offers a defence against the attacks of birds. Sometimes the outer layer is like the pericarps of fruits which have to protect the seed. It is as though Nature having become familiar with one good means for the protection and distribution of seeds here copies it to further the life cycle of parasites. In a like manner bitter juices, hard skin, furry coat and spines are developed on galls as on pericarps, and contribute to the remarkable resemblances between galls and fruits. Sometimes the resemblance is emphasized. The currant-gall which occurs on the catkins of oak, has not only the form and size of a red currant, but is succulent and bright coloured. The gall on the leaves of beeches caused by the beech-gall gnat is like a small plum, having a kernel in which the grub lives, a hard layer like a plum stone and a fleshy exterior.

Most solid galls are so constituted that when the contained insect is ready to emerge, it eats its way out, but there are some that carry their resemblance to seeds so far that they have developed contrivances for splitting open, to permit the emergence of the insect. Among these may be mentioned the gall produced by a gall-gnat on the leaves of the Turkey oak. In the early closed-stage, the gall is round and firm, embedded in the leaf, projecting on the upper surface like a tiny cone. In the autumn when the grub is full fed, the lower area of the gall falls away as cleanly as though a circular trap door were removed, and the larva tumbles out and makes its way to the ground where it spins up for its pupa stage. Next spring the gall-gnat emerges.

Baffling Relationship

There are questions raised in any speculative mind by such a relationship, so obliging on the part of the host-plant and so convenient for the parasite. Has such a relationship come about by the process which is ordinarily described as evolution? If so, here is an evolutionary development which appears to assist not the creature itself—the tree—but its parasite—the insect. What combination of chance mutations have contributed to this? Is there a providential purpose, favouring the gall-gnat at the expense of the Turkey oak, which latter is compelled to adjust its growing tissue to the service of a gnat? Is chance, in some miraculous way, responsible? Let the reader answer as his intelligence and wisdom decree, but in the meanwhile let him consider a yet stranger association.

There are galls produced in the cortex of a South American plant, *Duvaua*. The gall is spherical and hard. When the time is ripe for the caterpillar to escape, a plug with a projecting rim is developed on the side of the gall farthest from its attachment

—the most convenient place for the grub to escape from. This plug can easily be pushed out by the caterpillar and so allow of its escape.

And there is yet another case to provoke our wonder. On the leaves of the lime tree a short, tower-shaped gall is made by a gnat. In the gall-chamber lives the larva. This gall has an inner lining which is held within an outer protecting cup. As the larva grows, lining and cup become separated into an inner and outer gall; the inner gall is green and succulent, and the outer gall comparatively hard and of browner colour. Towards autumn the tissues of the outer gall become swollen at the base, exercising a pressure on the inner gall, which is shaped like a cone, narrower at the base than at the top. This pressure causes the inner gall to fall out on to the ground below the lime tree. The gnat grub continues for a short time to feed on the lining of the inner gall. It rests through the winter, and in the spring makes its escape by biting a ring-shaped groove below the conical top of the gall, so making a lid which can be pushed aside.

Selecting a Site

The position in which galls are formed depends on the insects which make them. They are, according to their species, very fastidious about the places they select. They search out places favourably situated as regards food supply, and likely to afford protection during the larval stage. Sometimes the egg is laid on the cortex, the leaf, the catkin, the stamens, or in the buds. Wherever it is, the place seems to offer appropriate nourishment and protection, each species selecting its own place on its own particular host.

The first question we have to ask is: "By what mechanism do these things come about?"

When the egg of the parasite is deposited on the surface of the plant, or in some cases within its tissue, very little change occurs. If the plant is wounded, the wound is healed in the ordinary manner. It is not until the larva comes from the egg that the changes in the growing of the plant take place. It has been suggested that the saliva of the larva stimulates, in this strange way, the cells of the plant to their abnormal growth. Also it is suggested that the excretion of the larva may be responsible.

What kind of substance is it in the saliva or in the excretion? We guess at the word enzyme. Some sort of enzyme, perhaps, perhaps a virus. Enzymes have the power of altering and decomposing substances, even through cell-walls. Whatever substances they are that are produced by the parasite do not kill the plant-cells, but stimulate it, as a cancer is stimulated, to an extraordinary new activity demonstrated in the formation of definite external forms.

But perhaps the solution of the question is not so simple, for not only is the protoplasm of the cells, directly acted on by the excretion, stimulated to an altered form of creative activity, but distant cells in ever-widening circles are also stimulated to

GALL-NUTS ON OAK LEAF

Gall-wasps which produce the various kinds of galls, or oak-apples, found on oak trees, belong to the family Cynipoidea. *They are highly specialized, small four-winged insects.*

participate in the new growth. To give an example. The spruce-fir aphis attaches itself to the scale of a fir bud. Not only are the cells in its near vicinity altered, but thousands of cells on the shoot soon begin to assume an altered form. We are reminded of the far-reaching influence of the spermatoplasm on the flower ovary. The spermatoplasm is only directly concerned with a few cells in the ovule, but as these propagate they influence the cells which go to make the carpels, the receptacle, and in some cases the flower-stalk. All these changes come about when the minute quantity of spermatoplasm in a pollen grain is united with a minute cell in the ovule. Something more than the influence of a *substance* seems to be evident here. In the same way it would seem that something beyond our ordinary conception of substance is at work in the modification of the host plant to the accommodation of the gall parasite.

There are yet further enigmas presented by the gall insects and their hosts. Let us take for enlightenment and bewilderment a plant which bears plum-fruits. When the leaves of this plant are invaded by leaf-lice, they no longer develop into the normal leaf, but assume the form of a carpel, and become fashioned into a hollow body deceptively like a seed pod. But seed pods have no connection with plum trees. It is as though the *idea* of pod (if there is such an idea as pod), has been borrowed in this case from another plant, and imposed upon the plum-fruit plant by the presence of the parasite.

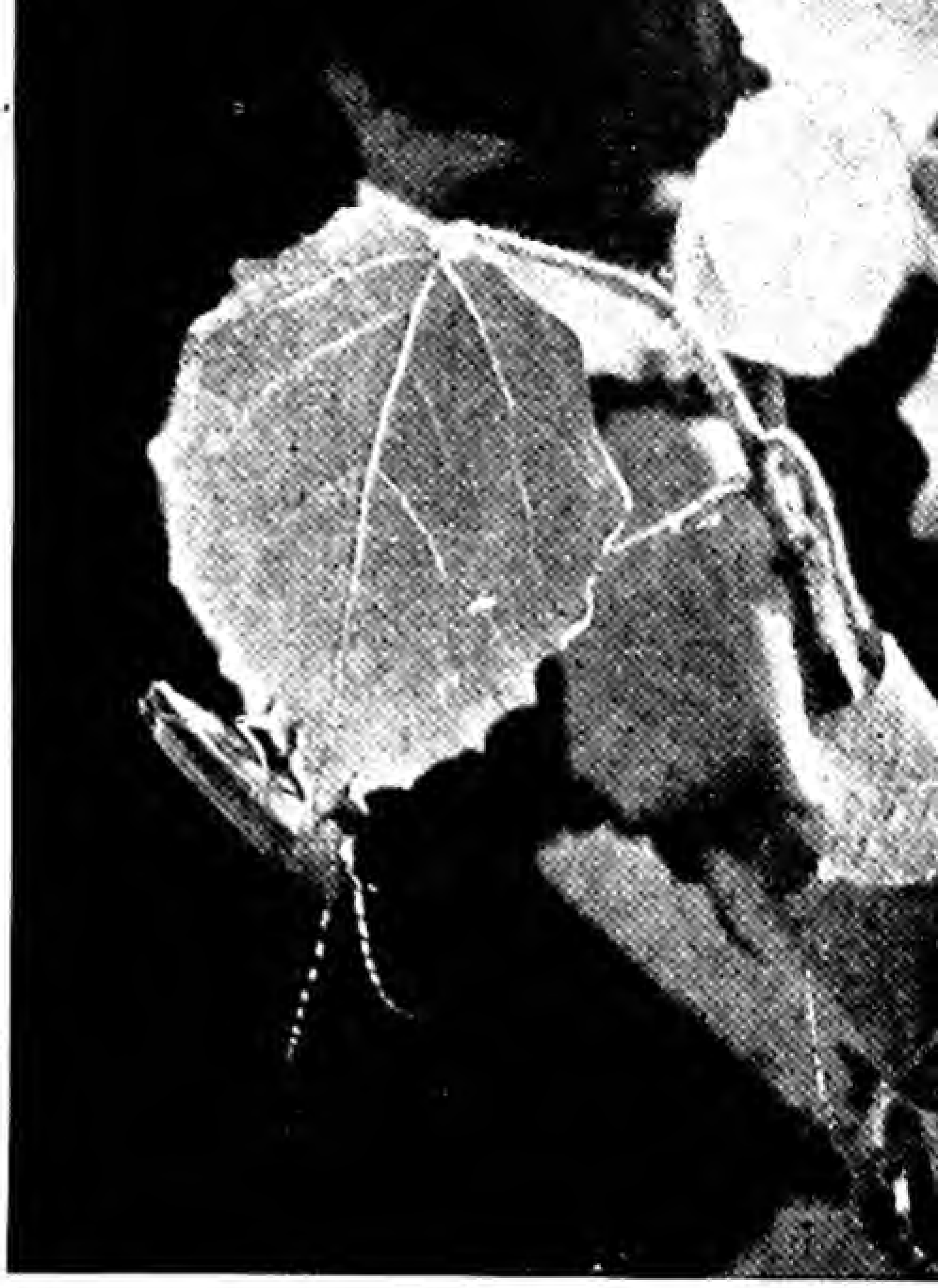
Examples such as this might be multiplied, and the remarkable thing, or rather one of the remarkable things, about such metamorphosis is that the growing tissues

GALLS OF CYNIPS KOLIARI

Striking clusters of bullet galls having the appearance of a bunch of fruit. Galls formed on twigs and branches usually originate in the cambium tissue.

ASPEN GALL-BEETLE

Not many beetles produce galls except as the result of mechanical injury. This insect shows preference for trees of the aspen or poplar family.



of the fruit-like body are always so devised as to be of maximum advantage to the animal which it contains. The dwelling serves for protection against weather and the attacks of foes, and as a source of food of the best imaginable kind.

Different Kinds of Galls

Significant also are the facts that different insects produce different kinds of galls on the same species of plants. Some kinds of oak bear as many as twenty different forms of galls produced by as many kinds of gall-wasps, and the shape, colour and hair-covering of these galls is so constant that one can say with certainty what species of insects have caused them. The fluids, substances or effluences emanating from different gall-producing insects are specifically distinct. The same vegetable protoplasm demonstrates how capable it is of producing different kinds of growth.

Is the characteristic pattern that is assumed by the gall, then, contained within the nature of the parasite? And here it is significant to note that one species of insect produces broadly similar, but slightly different galls on different plants, enabling us to answer the question, if not with complete satisfaction, at least in part.

Gall-insects are not always altogether parasitic. In some cases, though these are comparatively rare, the gall-fly performs a task that is partial payment for the benefits it receives. The small gall-wasp inhabiting the inflorescence of the fig tree is an example of a highly complicated partnership.

The fig, the fruit that one eats, begins as a complex flower, a collection of small flowers enclosed within a receptacle, which looks like a small urn. The mouth of the urn is very narrow. The flowers, of which there are two kinds, male and female, almost fill the entire cavity. The female flower consists of an ovary containing a single ovule. Some kinds of figs have two kinds of female flowers within the same receptacle; some with long styles and developed stigmas, some with shorter styles and abortive stigmas. These latter are called gall-flowers, for as we shall see, they serve the convenience of a minute gall-wasp and seem to have no direct function so far as the plant itself is concerned. Some species of figs contain both male and female flowers, some of the female flowers being gall-flowers. The latter are, as a rule, placed low down in the flower cavity and the male flowers are near its mouth.

In the flowering season the following extraordinary series of events takes place: a tiny wasp, *Blastophaga grossorum*, enters the narrow mouth of the container, crawls down the inflorescence and sinks its ovipositor down the style-canal of a gall-flower. It lays its eggs close to the nucleus of the ovules. The emerging larva preys on the ovules, and as it grows soon fills the whole cavity. When the metamorphosis of the male wasps is accomplished, they crawl out through a hole which they bite in the gall. They are wingless, and their task is to visit galls containing female wasps,

which they fertilize while they are still within the galls. These females later emerge, and escape soon after into the open air. In crawling up the inflorescence, however, the wasps contact the male flowers and become dusted with pollen. After emerging they let their wings expand and dry. They later visit another flower receptacle on a neighbouring tree or branch, seeking out inflorescences which are at an earlier stage of development than those from which they have emerged. Into these they crawl to lay their eggs, and in crawling down to reach the style canal of the gall flowers, they pollinate the others.

We have in this example of symbiosis an extraordinary adaptation. It is as if the gall-flowers are produced for the *express* purpose of giving a breeding ground to the gall-wasp. In return for this service, the wasp carries the pollen from one inflorescence to another. Our wonder at this complementary service would prompt us to question: how has it come about that the gall-flowers have been expressly prepared for the reception of the wasp eggs and the nourishment of the young wasp grubs? What combination of genes, segregating in the course of generations, and what possible conditions, could produce by chance such an adjustment?

The wasp is by no means always necessary for the reproduction of the fig tree, of which there are about six hundred species. More than fifty species of wasps, however, have been identified as transferring the pollen from one inflorescence to another. Some species of figs have their own particular kind of wasp.

Guest Animals

Within the gall produced by the gall-producing insect are sometimes found guest animals, or inquilines, who live in harmony with the gall-fly insects. These inquilines devour the plant-substance stimulated to growth by the gall-flies. In this way they may be said to offer a slightly disadvantageous association, but they do not in any direct way threaten the existence of the original occupier of the site. In contrast to the inquilines, there are

COMMON OAK-APPLES

This is probably the most commonly known type of oak-apple. It has a thin outer shell and a spongy interior. One of the galls is cut open to show the larval chambers.

YOUNG CUCKOO ASKS FOR MORE

The cuckoo's habit of leaving its offspring to be hatched and reared by another bird is well known. The pretty little foster mother in this instance is a hedge sparrow.

numerous parasites which prey on the gall-insects, and on these parasites there are hyper-parasites, also there are parasites and hyper-parasites infecting the inquilines.

Problem of the Cuckoo

If now we turn from so small and insignificant a creature as the gall-wasp to the self-advertising cuckoo, we shall find a story quite as baffling to any easily made assumptions. The cuckoos are well known to victimize certain other species of birds by laying an egg in the victim's nest, then leaving the egg to be hatched and the young cuckoo to be brought up by the fosterer. The fosterers are always birds which feed on insects. Pied wagtails, yellow wagtails, marsh warblers, robins, meadow pipits and hedge sparrows are the commoner kinds of birds victimized. The eggs of these birds are of varying colours, and it is found that the eggs of the cuckoo, which are larger than the eggs of the fosterer, though small for so big a bird as the cuckoo, vary in colour, often approximating to the colour of the eggs in the nest in which they are found. It was supposed, when the writer was a boy—and many reputable ornithologists still hold the opinion—that the cuckoo, having laid an egg, would turn round and have a look at it. If the egg were a greenish grey, it would pick it up and go in search of a meadow pipit's nest; if reddish in colour then the cuckoo would look out for a tree pipit's nest; if light grey, a pied wagtail. It would fit the egg it had laid to match the colour of the fosterer's eggs.

This assumption has now been challenged. Other ornithologists hold it to be wrong, and it is to Mr. Edgar P. Chance and his meticulous and long-sustained study of the cuckoo and her habits that we are chiefly indebted for another interpretation. He has given us a great many facts, and he has propounded a theory to account for them. First let us state in brief his facts, and then let us consider whether his theory, which is quite humbly advanced as only a theory, will in a satisfactory way explain those facts.

Mr. Chance has watched the nests of many fosterers of various species, but for the sake of simplification let us here consider only the case of the meadow pipit.

In early April the cuckoo arrives and gladdens us with the song which tells us that summer will soon be here. Meadow

FEMALE CUCKOO

Watching her opportunity to carry out her nefarious designs on a meadow pipit's nest. She must wait until both parents are absent from the nest.

pipits are building their nests and the hen cuckoo soon singles out a couple. She remains in their neighbourhood, watching them, and they are made unpleasantly aware of her presence. They will attack her and chase her away, for although the cuckoo is so large a bird in comparison to the pipit, she appears to be a cowardly one. Although she flees, she does not fly far, and soon returns, snooping about in the neighbourhood and becoming thoroughly conversant with the doings of the meadow pipits.

When the pipits have their nest completed and three or four eggs laid, then has come the time when the cuckoo must deposit her egg. She must deposit her egg before incubation by the mother pipit is due to start. She must choose the right time in relation to the biological cycle of the pipits, if her own species is to be propagated. Taking advantage of an occasion when the parent pipits are away from the nest, the cuckoo approaches, she picks up one of the pipit's eggs in her beak; she then raises herself over the nest and lays an egg; she then turns round and flies away with the pipit's egg still in her beak. At a convenient distance she perches, and eats the egg. Cuckoos are in the habit of stealing eggs from other birds' nests and eating them, but she does not steal from the nest of the selected fosterer, except on this one occasion, namely, when she is substituting her own egg for one of the clutch in the pipit's nest.

The pipit, although her behaviour has been markedly hostile towards the cuckoo, as though she suspected that something was wrong about the unwelcome attentions of this larger bird, does not resent the presence of the larger and slightly different coloured egg in her nest. Indeed, she would seem to cherish it. Should one of her own eggs be removed from the nest, she does not necessarily desert the nest, but should the cuckoo's egg be removed, then she will certainly desert.

Ovulation in Birds

At this stage in the story it may be well to consider the mechanism of ovulation in birds, the secretion of the yolk, of the albuminous white, and the secretion of the shell and pigmentation of the shell. The egg is budded off from the ovary into the coelom, and is swept into the funnel at the upper end of the Fallopian tube. As it passes slowly down the Fallopian tube it becomes impregnated by the male sperm, and in its passage it receives various additions. What is enclosed within the vitelline membrane is the true egg; the white and the shell which surround it

constitute a kind of cocoon, the white for the further nourishment of the developing embryo, and the shell for protection. These layers are secreted by the lower portions of the Fallopian tube. Last of all, when the shell is formed, the pigmentation, when there is pigmentation, is added. The addition of the colour occurs in the last stage before the laying of the egg. The colouring is usually of a specific character.

There are exceptions to this rule, as for example the guillemots, whose eggs are of varying colours and designs. The cuckoo also, like the guillemots, though in a different way, would seem to have the capacity to lay eggs of different colours, since some cuckoos lay eggs resembling meadow pipits, and others lay eggs which resemble those of other foster parents.

How is it this pigment is formed so as to match the pigmentation of the fosterer's eggs? It is presumed that this coloration is of advantage. Is it purpose or chance which makes for this uniformity in the coloration of the eggs of such different species as the cuckoo and the pipit? Are we justified in the assumption that the perceptual functioning of the cuckoo has some effect on the sort of pigmentation that is laid down by the lower portion of the Fallopian tube on the shell of the egg? Or are we to assume that the coloration of the eggs of the cuckoos is determined by genes? Whichever way our thoughts incline, we are met with considerable difficulties.

Mr. Chance, who has perhaps studied the cuckoo more thoroughly than any other observer, is of the opinion that the female cuckoo tends to victimize the same species of foster parent by which she herself was reared. He bases his theory on the conjecture that the young cuckoo would carry certain memories of its foster-mother, and, on seeing members of that species again, would wish for further association. He suggests that in this way races of cuckoos may exist within the species, and that there are meadow-pipit-cuckoos, reed-warbler-cuckoos, wagtail-cuckoos, etc. He claims that there is a good deal of evidence for such a supposition, and that nothing can be urged against it. If such races of

CUCKOO WITH PIPIT'S EGG

This remarkable picture shows the cuckoo flying off with the meadow pipit's egg, having deposited her own in its place. She will devour it later at her leisure.

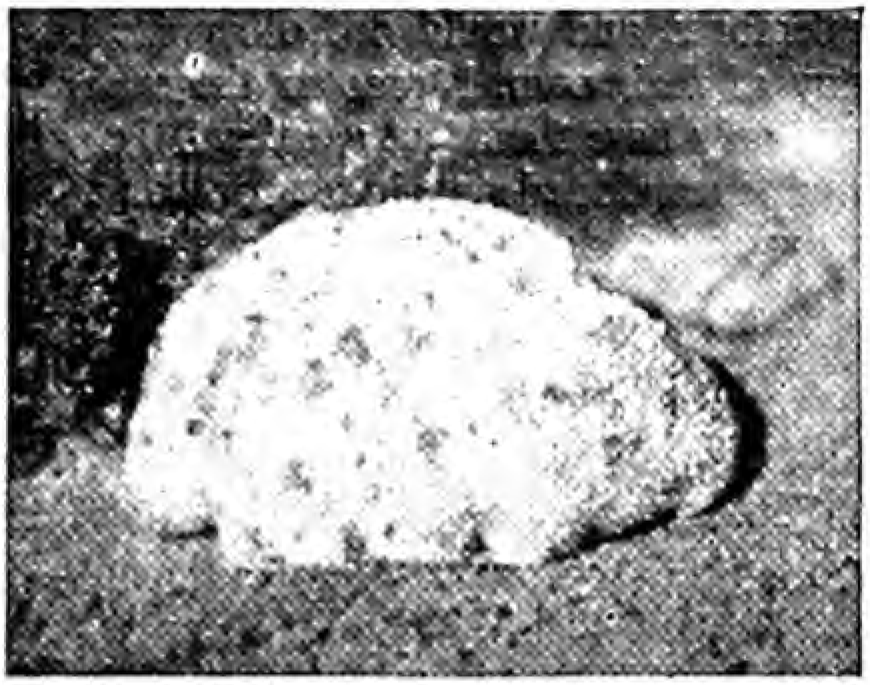
cuckoos really exist, then in the course of generations their characteristics in relation to their eggs will become fixed, and it will be that the meadow-pipit-cuckoo lays an egg resembling the meadow pipit's egg.

Mr. Chance is not blind to what this assumption implies, namely, that the male cuckoo must be equally involved; for the inheritance, according to orthodox ideas, goes through the male as much as through the female. Therefore, if there is to be anything in this theory there must be male meadow-pipit-cuckoos which by preference pair with female meadow-pipit-cuckoos. If this were not so, the races would be blended. He asks us to suppose that it is so. It may be, but it seems somewhat improbable, and very improbable that such selective breeding within a species should continue for long periods embracing many generations. If there were just a few mismatings among the races, then other characteristics would be introduced to mar the pattern.

There are, however, other theories and facts at variance with all these theories. There are ornithologists who differ from Mr. Chance, who do not believe that the cuckoos always lay their eggs direct into the nest of the fosterer. Besides those who believe that the eggs are placed in the nest by the beaks of the mother cuckoos, there are those who believe that the nests of the various fosterers are inacceptable to the laying method. There are among foreign cuckoos species that lay their eggs in the nests of birds which they could not possibly sit in or over, for example, the tailor-bird's nest, made from a single leaf whose edges have been sewn together. It sways in the wind and its entrance hole is in the bottom of the nest. This nest sometimes contains cuckoos' eggs and young cuckoos. How can the egg have got there? It must, so argue some experts, have been projected in, squirted in, the cuckoo clinging to the nest, placing its cloaca against the entrance of the nest and projecting the egg in. This may seem a difficult feat and difficult to believe in. Yet the

TRAPS FOR THE UNWARY

Each of the long, waving tentacles of a sea-anemone is covered with stinging cells, or nematocysts, which explode at the slightest touch, releasing thousands of tiny poisoned barbs.



SEA-SLUG

Right way up and (below) upside down. The brightly coloured projections, or papillae, which cover it, are often provided with nematocysts obtained from the sea-anemone.

question remains: how did the cuckoo's egg get there?

There are yet other difficulties which cannot be accounted for by the projection theory, even if we accept it. And Mr. Chance himself admits that "there is no doubt that many cuckoos do not lay in the nests of their dupes, since their eggs have been taken from nests in holes to which it would have been impossible for the parasites to have obtained access for the purpose of laying." How do the eggs get into these places where no cuckoo could possibly lay them? A fairly large number of such instances are on record and are vouched for by reputable ornithologists. The enigma of the cuckoo remains as yet unsolved.

Sea-Slugs and Sea-Anemones

Perhaps the most remarkable and the most insoluble of the problems that present themselves amongst the life histories of animals is the pattern of inter-relatedness composed by the sea-slugs and the sea-anemones on which they feed. Sea-slugs inhabit those shallow reaches of the sea shore that are exposed at low spring tides. Many of them have brilliantly coloured papillae or appendages growing from their backs, and in these are found groups of curiously formed stinging cells, which are believed to function as defensive weapons, and which protect the slugs from the attacks of fishes. If a fish snaps at the bright coloured appendages, he will probably receive in his mouth a discharge of nettle-cells which will send him away discomfited, and prevent further attack. (Some species of fish, however, such as the cod, can devour sea-slugs with impunity.)

Nettle-cells, or (to give them their scientific name) nematocysts, are of course, part of the living body of the anemone. But they have extraordinary characteristics, for, when the skin of the anemone gets the slightest touch, the cells are released with an explosive jerk and shoot into the intruder. Put your finger in among the open tentacles of any of our seashore polyps and you will be prickled by their thousand-fold tiny barbs. Such a weapon is no doubt both protective and offensive; it would tend to drive off the enemies of the sea-anemones and also to disable or poison the small creatures upon which they feed.

Scientists had believed that nematocysts were to be found only in the *Coelenterata* group, which includes the sea-anemone and jelly-fish. But it was discovered that nematocysts were also to be found in the papillae of sea-slugs, which belong to the *Mollusca* group. This suggested an unexpected and close affinity between the *Mollusca* and *Coelenterata*.

The presence of the nematocysts in the sea-slugs, however, has been carefully studied by marine biologists and proves more remarkable than any family relationship. For the sea-slugs, it was discovered, *get* their stock of nematocysts from sea-

anemones and would not otherwise have any of their own. Moreover the sea-slugs not only *have* them but *use* them. They lie in an unexploded state in the papillae of the slugs and shoot out at a touch in exactly the same way as when in the body of their original owners.

How Does the Sea-Slug Do It?

This much is known, but much is still obscure. The sea-slug actually eats the sea-anemone, nematocysts and all. How is it that the nematocyst which explodes at the least touch, is *not* exploded by the sea-slug in the process of being devoured? How is it that the harsh, saw-like radula of the slug, with which it *tears* its food, does not break the sensitive capsule of the nettle-cell? It has been suggested that the slug, in eating, exudes mucus which prevents the discharge of the nematocysts, but is this sufficient explanation? Why are not the defensive cells discharged on the approach of the slug? They are discharged in some cases, but not in all. Why not? And how is it that the slug itself is immune from the poison? Mr. A. C. Glaser writes: "It is truly remarkable that these apparently helpless creatures (the sea-slugs) should have selected such a dangerous prey, but since they have, it must be because the danger does not apply to them. Why it does not, I do not know, but it may well be that for the same reason the nematocyst does not discharge while being eaten." Those reasons, whatever they are, remain obscure.

The next mystery is: how is it that the unexploded, and only the unexploded nematocysts, are gathered together from out of the stomach of the slug into narrow ciliated channels, and are swept by the working of the cilia, extremely minute hair-like filaments, up into the tiny pouches which lie near the periphery of the brightly coloured appendages, and how is it that they are there neatly arranged the right way up, in such a manner that they can discharge themselves against any intruder which threatens the peace of the sea-slug? How is such a complicated and highly specialized sequence of events to be accounted for?

"But is this really true?" the reader will ask. "Are you sure of the facts? Surely it is only reasoning, reasonable men who can steal the offensive weapons of weaker creatures to use for their own purposes!"

The facts have been most laboriously investigated. Mr. G. H. Grosvenor has proved that the nematocysts found in sea-slugs and coelenterates are identical in plan and construction and in mode of discharge, and that nematocysts of several distinct types occur in both groups; also that a single type of nematocyst does not occur uniformly throughout any one species of sea-slug, but that different individuals of the same species may have quite different nematocysts according to the food. He has also proved that a single individual sea-slug may have within the pouches on the dorsal appendages, nematocysts of several different types, found in distinct groups of coelenterates . . . and further that, when it is known on what coelenterates a sea-slug has been feeding, then the nematocysts in the two are identical. Also he has proved that sea-slugs which feed on animals which have no nematocysts, have themselves no nematocysts. He has also traced the courses of the ciliated canals which pass from the diverticula in the stomach to the pouches on the dorsal appendages, and he has conclusively proved that the nematocysts in any particular sea-slug can be changed after a change of diet.

The facts are established, but the question of how this truly remarkable state of affairs has come about no one has answered, nor has any theorist tried to explain how any such unique combination of characteristics *comes to be evolved.*

Riddle Unanswered

The patterns of life that have been described in this chapter are but a few selected from a very large number of such patterns that are not easily explained by any theory of evolution. Nor are they easy to comprehend should we suppose that they are the expression of deliberate acts of creation. All we can safely say is that, in trying to grasp at a significance, we have felt the slippery tail of the Eel of Science passing through our fingers. Can any reader hold it, or has it escaped?

GUIDE TO FURTHER STUDY

When the reader has reached the end of the last chapter, it is as well that he should ask himself a question or two. Has the reading of this book merely been something to pass the time, to fill in an idle moment, and then to be forgotten, or has it aroused sufficient interest to make him want to go further with the subject of biology, to study it and to probe its mysteries for himself?

We hope that the knowledge which he has gained, however slight or incomplete, will have been sufficient to fire him with enthusiasm for this enthralling subject. After all, the reader is himself a part of the world of living things. What happens in it, happens to him. He is in a state of symbiosis with every other living thing. So, when one studies the world of living things, one studies oneself and one's own life as well—a thing to remember if one decides to carry on the study of biology beyond the end of the last chapter.

The reader is advised, then, to be quite frank with himself and to be certain of a lively interest in the subject if he would take up its study. He is warned that there is a lot of tedious detail—just as in every other branch of learning—which he will have to master some time or another. There is a tendency today, in books, lectures and wireless talks, to skim the cream off a subject, as it were, to make it more interesting and exciting, leaving a lot of skimmed milk behind for the student to absorb for himself. Just as in other walks of life, other endeavours, there is no short cut to success, so is it in following up any of the subjects raised in this book. But the result is worth the effort.

What parts of this book appeal most to the reader? Is he interested in plants or do these appear uninteresting things only studied by priggish people of both sexes? Is it animals which move him to admiration or are they dull, brutal objects which fill him with repugnance? Or, finally, does the study of mankind appear the only proper study; or does it seem a bit indecent to investigate the inner workings of man's body and mind? This last view is by no means rare. The study of anatomy and, consequently, of physiology, was held up for hundreds of years owing to prejudice and, in the last forty years, the study of psychology has been greatly hindered because people objected to groping about in their own and other people's minds.

Whichever side of biology it is proposed to study, much preliminary work can be done out of doors.

In the fields and woods and lanes of the countryside, the student can observe plants and animals for himself, study their habits and learn to identify them. This will develop his power of perception and add greatly to the enjoyment of country rambles.

In the study of botany, especially, outdoor work is essential. It is useless trying to learn it from books alone. If one does, botany remains merely a mass of facts and never comes alive.

Collecting things is a hobby which many people enjoy. Here, biology offers an almost unlimited scope, and many ideas will occur to the student apart from those suggested in the following pages. The difficulty is to know where to begin.

Study of Plants

Let us suppose that plant life is the side of biology which the reader proposes to investigate. An excellent idea for a beginner, though it may sound a little alarming, is to start a herbarium. When you take your walks in the country, collect specimens of flowering plants in a closely-fitting tin box (vasculum is the correct name) and in the evening identify your specimens with the help of a book on flowering plants, noting their English, as well as their botanical names. Press good examples, with flower, leaves and roots

CAMPIONS

Two members of the campion family which grow wild in Britain. Red campion (above) and bladder campion (below). Both flower throughout the summer.

intact, between blotting paper until dry, and mount them later on sheets of drawing paper. Of course, if you have a good memory, there is no need to press the plants, but, in this case, you should make accurate drawings of them, particularly of the flowers and fruits.

Identifying Plants

All this is merely to get you into the alphabet of the subject—nothing more—and it may be given up as soon as you recognize infallibly some one to two hundred plants. It is amazing what mistakes one can make at first in identifying plants. Three different attempts on the same plant may lead to three different identifications! But a sense of humour and a refusal to be discouraged will work wonders. Do not attempt difficult things, such as the grasses, at first—what to most people is just "grass" is, to the botanist, a mixture of dozens of different grasses: poas, fescues, agrostes and many more. Pursue only the plants with very obvious flowers at first—the more insignificant can be left until later.

When you begin to know your way about among plants, so that you know, say, the greater and lesser stitchworts and relate them to chickweeds, you can drop the herbarium (which may easily prove a deadly snare) and start following up some one or other family of flowers. You can collect the poppy family and see the relation in appearance between the greater celandine, the Welsh meconopsis, the opium poppy, the field poppy, the horned poppy and the garden Shirley, Iceland and Oriental poppies, eschscholtzia and *Romneya coulteri* and the Tibetan meconopses. Or you can chase the pea and bean family through their various ramifications of trefoils, clovers and vetches.

Another suggestion is the collecting of leaves of trees. You should take a notebook with you and jot down particulars of the

kind of leaf, or leaf arrangement, palmate, digitate, alternate, pinnate, and so on; also, information about the tree itself, its shape, size, height, type of bark and fruit and where found. Soon you will readily identify all the trees common to your part of the country. When the leaves have been dried between sheets of newspaper, you can mount them in various ways or glue them on to sheets of paper.

Similarly, collections can be made of seeds and fruit, twigs and buds, roots and stems, or unusual features, such as galls. Other suitable subjects for collections are ferns, mosses and fungi, all of which are found mostly in woods. Fungi of the mushroom type are not suitable for drying, but they can be preserved in a solution of seventy per cent alcohol or two per cent formalin. Spore prints can be taken of the cap forms. Cut off the ripe cap and place it face downwards on a piece of white paper. Cover with an inverted glass and let it stand for at least twenty-four hours. When the cap is removed, you should have a clear imprint of the underside of the fungus, showing the arrangement of spore-bearing gills and the colour of the spores. The print can be preserved, if desired, by applying a thin coat of shellac.

Of course, making collections is only the beginning of botany, though it can be quite absorbing and exciting. And you can go on from it to more ambitious work. For example, you may investigate for yourself just how plants struggle towards the light or spread their leaves out to catch the maximum light; how the lazy ones climb in and through and around the sturdier plants, using hooks, thorns, twining tendrils, suckers and so on to achieve their places in the sun; how the leaves are arranged in a mosaic so as to catch the utmost sunlight.

Keeping a Diary

Or you may keep a diary to show when such a family as the pinks and campions flower. Of course, the text books tell you that, but it is more fun to find out for yourself, especially when the seasons run riot. For example, a cowslip may be in blossom under the nose of winter, in October. It is carrying a rosette of seed vessels which ripened last May. A very wet summer has betrayed it into contradicting the text books and causing people to write to the newspapers.

Finally, you can go on to experimentation. With very little apparatus beyond a few glass bottles, cotton wool, ink and some wire, you can study growth in a germinating broad bean, watch its root turn down and its leaves turn up. You can sterilize a square yard of surface soil in a garden by pouring several kettles of boiling water over it, or by watering it thoroughly with one per cent formaldehyde solution, and record what, and in what order, plants appear on your patch. A director of Kew Gardens made the most illuminating observations on the way plants colonized the blitzed areas in London. Best of all, perhaps, you can make experiments in cross-breeding garden plants—for example, repeat Mendel's experiments with garden peas, or hybridize flowering plants.

The experimentation you can do among plants is endless and fascinating but it needs perseverance, patience and much common sense. The results are worth the effort.

Specialized Gardens

If you have the space, you may care to make specialized gardens, in which you can give rein not only to your horticultural experiments, but to your artistic sense as well. A rock garden occupies little space and will accommodate a surprising variety of plants.

An old-fashioned herb garden is fascinating, and will provide a side-line of study in connexion with the medicinal or flavouring properties of the plants you grow.

A water garden provides infinite possibilities. If you make a pool, it should be about two feet deep and lined with concrete. You should have a few animals—goldfish, snails or frogs—to keep the water clean. Make the setting as attractive as possible, with plenty of flowers. If the pool is fed from a stream, you can build a little bridge over it, or stepping-stones, and grow reeds and ferns and forget-me-nots on the banks. In the pool itself, you can grow water-lilies of various colours.

Perhaps these schemes are altogether too

ambitious for the space at your disposal. Even in a small garden, or a yard, you can have a tub garden. A tin-lined wooden packing case, or old galvanized bath or sink can be used for the pond. Dig a hole and sink the tub so that the top is just above the ground, and half fill it with earth. Fill up with water and then plant your water-lily or what other water plants you decide on. Lastly, a layer of sand spread over the earth at the bottom is advisable, to prevent the water becoming cloudy. A border of flowers in a setting of crazy paving, or similar material, will make a charming little formal garden.

Failing a garden, or even a yard, you can plant window boxes or have indoor gardens. Spring-flowering bulbs lend themselves particularly well to indoor cultivation, but there are many small, low-growing plants that will also grow quite well in a shallow bowl. Geraniums and other plants that can be propagated from cuttings take kindly to an indoor life.

Animal Collections

Plants perhaps bore you and it is animals you like? Again, the field is pretty well limitless. As a beginner, you will probably start collecting, say, butterflies, moths or beetles. This is not a bad way into the subject so long as you do not develop collector's mania, and collect only in order to accumulate. It should lead to a study of the life histories of the animals collected and the breeding of them from egg to maturity, and thence, possibly, to experimentation.

Keeping an aquarium is great fun, even if it consists only of a jam-jar full of minnows or tadpoles, such as small boys love.

If you can afford to buy a proper aquarium tank, so much the better, as it will offer more scope and you may acquire a collection of plants and animals that will be very beautiful to look at, as well as interesting to study. But if you cannot obtain a tank, use any sort of suitable container; for instance, a glass battery jar. It is advisable to get water from a pond or stream for your aquarium and put a layer of clean sand at the bottom before putting in the plants. You can collect the plants yourself from a pond, or you may be able to buy some from a nurseryman. Wait until your plants are well established before introducing the animals and be sure not to overcrowd the aquarium.

A more modern hobby is that of bird watching. This is, in its inception, really a form of collecting, though you do not kill and stuff the birds you collect. In the beginning, it needs little more than patience and good eyesight, plus a book giving coloured illustrations of common birds. In the neighbourhood of towns, allowance must be made for dirt and also "melanism"—birds, and moths, get darker in colour near smoky towns. For instance, the so-called English sparrow, known to Londoners as a little, dark-brown bird, in the wilds of Canada will be found to have quite distinctive red-brown markings.

When the leaves come on the trees before the migrants appear, bird watching is not easy without field glasses, and to use field glasses properly one often has to lie down. In an erect position, especially if the magnification is 6 x or over, movements due to the wind or contractions of the muscles make accurate vision impossible. Lying down in the English countryside, long enough to take stock of a bird, means that you will often become cold, wet, tired, bored, disappointed and hungry. But a keen bird watcher will put up with worse than these discomforts—Julian Huxley, for example, endured mosquitoes and humid heat in the swamps of Louisiana.

Nature Photography

From bird watching one graduates to bird photography—or, rather, nature photography—fortunately, today, much more achievable than it was some few years ago, what with miniature cameras with telephoto lenses and extremely rapid panchromatic films.

An expensive camera is, however, by no means indispensable. Excellent nature photographs can be obtained with an ordinary small camera, if sufficient care is taken. The amateur should start with pictures of plants or scenery—things which do not move, except, perhaps, as a leaf is stirred by the wind.

Photographing birds and animals re-

quires plenty of patience and often considerable ingenuity. You may have to crawl stealthily through undergrowth to snap a wild creature, or climb a tree to take a bird on the nest or feeding its young. You will be able to get hints on this type of photography from magazines or books on nature.

Bird watching, and animal watching, do not necessarily imply the wilds. Domestic animals can be the field of operation. Observation of the poultry yard shows that there is a definite "pecking order." The turkeys peck the geese, the geese the ducks, the ducks the hens, the hens the chickens. A similar hierarchy is found among the cows in the cowstalls. This pecking order often seems to be related to colour rather than size or species. In most human societies (families, schools, university colleges), there is a "pecking order," too!

Experiments are by no means out of the question. Most people have bred animals —mice, rats, guinea-pigs, rabbits, fowls, cats or dogs. In breeding, the fundamental facts of genetics can be verified and even possibly extended, though it is rare to find a piece of elementary exploration that has not already been done.

Working Apparatus

Further work in either botany or zoology is likely to need a microscope, and here one meets the difficulty of expense. No microscope is worth while which is not of high rank, and the simplest student microscope costs a considerable sum today. High magnification is not needed. Two eye pieces, two objectives (2/3-inch and 1/6-inch focal length) are all that is necessary for anything but advanced work. Substage condenser and a mechanical stage are of use for special purposes but are rather encumbrances on a workaday microscope.

For plant work, little more than a heavy, flat razor, some pith, slides and cover slips and a little iodine solution are necessary, for with these and a microscope, the structure of a leaf, root or stem can be adequately made out. But, with animal tissues, it is almost essential to have more elaborate apparatus, including embedding bath and microtome and all the special reagents for staining, clearing and mounting the sections. This is really specialist's work and it is seldom that an amateur, without laboratory training, gets any distance in the technique of preparing specimens for the microscope. Much, however, can be learnt from watching the behaviour of the tiny animals seen in a drop of pond water, or in an infusion of hay—made much as one makes tea and allowed to stand a few days —under low magnification.

So far, the plan of campaign sketched above has covered only work to be carried out by the student himself, without the aid of books, classes and so on. Up to a point, this is the best possible way to learn, for what a person discovers for himself impresses itself on the memory and generally remains with him for life, while things that are learnt from books are often all too soon forgotten.

Books on Botany

But the science of biology, as we know it today, is the outcome of centuries of study and research by eminent men of many nations, and it would be quite impossible for any one person in his own life-time to discover for himself even a fraction of the knowledge that has been accumulated. Therefore, if the student wishes to study the subject at all deeply, he must do a certain amount of reading. Here are the names of some books that will be a help to him, to be used primarily as books of reference, not necessarily as books which are read from first page to last.

If you can get hold of it, *Botany for Fun*, by Gareth H. Browning, is an elementary book which will give a good introduction to botany. *Plant Biology*, by H. Godwin, is a more scientific production, covering the whole field of botany from microbes to flowering plants. It is a small but very valuable text book. The best book, which is both scientific and interesting from the point of view inculcated above, is *Plant Form and Function*, by F. E. Fritsch and E. J. Salisbury, but it is emphasized that it need not be read from beginning to end.

A book of this sort should be approached via the index. Take any topic which interests you—for instance, how plants climb—and look up "climbing plants" in

KEEPING AN AQUARIUM

Tadpoles and pond-weeds in a water tank. Some beautiful effects can be achieved with under-water plants and it is always interesting to watch them and the animal life developing.

the index. Note the important references in the index, and then turn them up. Any interesting point, go and verify at once in the garden or the hedgerow, if you can. When the main references are finished, look up the smaller and less important ones. Finally, if you really want to make it your own, put down on paper in your own language all you have learnt in, say, not more than five hundred words, and illustrate it.

Some time or other you will use a book such as Bentham and Hooker's *British Flora*, and there are two books, brought up to date, familiar to many a schoolboy and undergraduate, viz., *Flowering Plants* and *Flowerless Plants*, by D. H. Scott and F. T. Brooks. *The Living Garden*, by E. J. Salisbury, is another admirable book, which has gone through many editions.

It is well to pay a visit to the reference library in your own neighbourhood. If access to the shelves is allowed, as it is in most libraries, you will be able to browse among the books there. Realize that books have a way of getting out of date and, while some will remain valuable for all time, most will be valueless after a few years. Consequently, many on the shelves will have antiquarian value only and, unless the librarian has had a scientific training, he will not be aware of this.

Turning to animals, it is suggested that the reader starts with *Enigmas of Natural History*, by E. L. Grant Watson. Any article on natural history by Julian Huxley is well worth study, but his more theoretical works, for instance, *Evolution; the Modern Synthesis*, are rather terrifying to the beginner. *The Science of Life*, by H. G. Wells, Julian Huxley and G. P. Wells, is a weighty, though fascinating book. Too fascinating, in fact, for it encourages the reader to do his natural history sitting in an armchair. The same is true of all of Fabre's books on insect and other life.

An old-fashioned book on birds is *A Year with the Birds*, by W. Warde Fowler. Of matter-of-fact interest are *British Birds in Their Haunts*, by C. A. Johns, J. A. Owen and Wm. Foster, *Birds in Flight*, by

W. P. Pyecraft and *Birds in Britain Today*, by G. C. S. Ingram and H. M. Salmon. The naturalist, Grant Watson, quoted above, recommends *The Nature of a Bird's World*, by Elliot Howard, any and all of W. H. Hudson's works, *Behaviour of Animals*, by E. S. Russell and any of Fraser Darling's books: *A Herd of Red Deer, Island Years and Wild Country.*

Physiology and Psychology

As regards physiology, Chapter VIII, which deals with the workings of the human body, and psychology, Chapter IX, which deals with the workings of the human mind, there is some difficulty in recommending further study. First of all, there are no really elementary studies of either which are both elementary and sound, except perhaps *Human Physiology* by Kenneth Walker. Secondly, any practical work in physiology needs a laboratory and laboratory apparatus. True, there are some simple experiments a person can perform on himself, but much of the study of physiology depends upon rather expensive apparatus. The text books on that subject are written for medical students and lecturers in physiology.

There is, or was, an *Elementary Physiology* by T. H. Huxley, edited by Sir Joseph Barcroft. The text books used by medical students are *Handbook of Physiology* by R. McDowall, *Applied Physiology* by Samson Wright, *The Physiological Basis of Medical Practice* by C. H. Best and N. B. Taylor and *Principles of Human Physiology* by C. E. Lovatt-Evans. The last two are almost encyclopædic in content and size. Practically none of them should be read except in conjunction with a course of lectures by a competent physiologist, and only the latest editions are of real value. Physiology and biochemistry change too rapidly for any but the latest publication to be read and believed!

In psychology, the reader is warned that there are two separate branches which have not altogether grown together again. There is the old classical psychology which relies largely upon introspection, observation and on physiological experiment. This is probably best studied in books by William McDougall, such as *An Outline of Psychology*, *An Introduction to Social Psychology* and *An Outline of Abnormal Psychology*. The reader is warned that these "outlines" are more like studio pictures and the "introduction" more like a complete guide, and it is suggested that they be read in conjunction with a course of lectures on psychology.

The newer psychology, but not necessarily the more credible psychology, is that based upon analysis. If the reader can get hold of it, *The Psychology of Insanity* by Bernard Hart is a very simple introduction. It is more about the psychology of everyday people than of the insane. Failing that, there is the *Psychopathology of Everyday Life* by Sigmund Freud and *Totem and Taboo*. The one-sided view presented by Freud should be corrected by reading *Psychology and Morals* by J. A. Hadfield and *Modern Man in Search of a Soul* by C. G. Jung.

Heredity

For students who are interested in genetics, we can recommend any of the following books :

Heredity, Race and Society, by L. C. Dunn and T. H. Dobzhansky. A popular small volume dealing with the special genetics of man and with the relation of genetics to social problems.

Mendelism and Evolution, by E. B. Ford. An excellent introduction to genetics.

The Genetics of the Mouse, by Hans Gruneberg. Though dealing with the special genetics of the mouse, it is an introduction to general genetics.

The Causes of Evolution, by J. B. S. Haldane. Stimulating, simple and philosophical.

Nature and Nurture, by L. Hogben. Somewhat mathematical and advanced but well worth reading.

You and Heredity, by A. Scheinfeld. A most excellent popular account.

An Introduction to Modern Genetics, by C. H. Waddington. A serious and successful attempt to relate genetic fact with the phenomena of development.

The Chromosomes, by M. J. D. White. One of the best small manuals on the subject.

ANSWERS TO "TEST YOURSELF"

The set of questions at the end of each chapter is meant for the most part to test the amount of factual knowledge which you are able to retain from your reading. Do not be surprised if you find that you are not able to answer many of the questions after one reading. You would be rather exceptional if you could. What is worth studying is worth several readings; and the test questions will be a useful guide to your progress.

CHAPTER I

1. Living things grow by incorporating materials quite different from the materials of their own bodies. Non-living things (e.g. crystals) grow, but only by the addition of material identical with that of which they themselves are composed. Living things move (animals), feed, respire, excrete (animals), reproduce. Living things have a definite span of life—birth, youth, maturity, old age, senility, death. Non-living things may continue indefinitely to exist unchanged.

2. Movement is necessary if animals are to find their food. A nervous system increases an animal's sensitivity to what is going on in the environment. Plants, lacking a definite nervous system, possess this sensitivity to a lesser degree.

3. Plants take in simple chemical materials—carbon dioxide from the air and water and mineral salts from the soil—and build these up into complex chemical materials by photosynthesis. Animals, lacking the chlorophyll characteristic of the majority of plants, are unable to do this. They take in the complex chemical materials of animal and plant bodies and convert them to their own purpose.

4. Protoplasm is the living matter which constitutes a varying proportion of the bodies of animals and plants. It may be associated with non-living material, e.g. bone in animals, wood fibres in plants. Chemically, it is a complex mixture of organic compounds, water and salts. Physically, it is an emulsion.

5. A cell is a living unit. Some organisms consist of only one cell, but the majority of organisms consist of very many cells. Each cell contains living protoplasm, divided between the nucleus and the surrounding cytoplasm. When the cell reaches a certain maximum size, it divides into two, the nucleus dividing before the cytoplasm. Groups of cells may specialize in performing one particular function, e.g. digestion, contraction, conduction of nervous impulses.

6. The two chief waste materials are carbon dioxide and nitrogen compounds, like ammonia or urea. The carbon dioxide is got rid of by gaseous exchange in the respiratory organs (gills, lungs, etc.). The nitrogenous waste is eliminated by the excretory organs (kidneys, etc.).

7. Animals and plants assimilate (in different ways) materials into their bodies. If this assimilated material exceeds the amount required for replacing used-up material, growth results. If it balances it, growth no longer takes place. If it falls short of this requirement, senility sets in and, later, death.

8. Roots are below ground. Their branches are all alike. Near their tips are groups of root-hairs. The water-conducting tissue is near the centre, and this helps to withstand the pulling strain to which the root is subjected. Stems are above ground. Their branches are of different kinds (stems, leaves, etc.). The water-conducting tissue is near the outside, and this helps to withstand the bending strain to which the stem is subjected.

9. Because it enables the plant to utilize the energy of the sun's rays to build up the simple chemical substances, carbon dioxide and water, into the complex chemical materials, sugar and starch. Plants not possessing chlorophyll are unable to carry out photosynthesis in this way.

10. Carbon is obtained from the carbon dioxide of the air. This enters through the stomata of leaves and stems. Oxygen; too, comes from the air, and enters in the same

way. Oxygen is also a constituent of carbon dioxide (CO_2) and water (H_2O).

11. In the daytime green plants utilize the energy of the sun's rays to photosynthesize sugar and starch from carbon dioxide and water. Oxygen is a by-product. Respiration goes on at the same time, but is masked by the evolution of this oxygen in excess of the amount required for respiration. The carbon dioxide formed in respiration is utilized in photosynthesis. At night, when photosynthesis ceases, respiration becomes apparent, oxygen being used up and carbon dioxide given off.

12. Lacking green chlorophyll, bacteria and fungi cannot photosynthesize. They obtain their food in complex organic form. Those living on living organisms are parasites: those on dead and decaying organic matter, saprophytes.

CHAPTER II

1. When no attempt is made to classify animals carefully and scientifically, you may have one animal known by different names in different parts of the world, or even in the same country. Equally, you may have the same name given to quite different animals. The present method of assigning to each animal a generic and a specific name was invented by Linnaeus.

2. Ten. An example of naming one animal from each phylum is: Amoeba (*Protozoa*), bath sponge (*Porifera*), jelly-fish (*Coelenterata*), liver fluke (*Platyhelminthes*), lug-worm (*Annelida*), limpet (*Mollusca*), spider (*Arthropoda*), starfish (*Echinodermata*), sea-squirt (*Protochordata*), dogfish (*Craniata*). Other examples, of course, could be given.

3. The *Protozoa*, animals which consist of a single cell, although they may have more than one nucleus. Examples are amoeba, the slipper animalcule and the malaria parasite.

4. Sponges have a complex system of tubes and spaces lined by cells bearing flagella. These beat and set up currents, drawing water in from the outside. This water brings tiny animals and plants into the sponge, and it is on these that the sponge feeds in a truly animal manner. Sponges are of no great food value to other animals, as so much of their bodies is hard skeletal material. It is this skeletal material which is of use to man in cleaning himself by rubbing his skin with it.

5. Oyster, mussel, scallop, snail. The oyster, for example, feeds by filtering off the minute animals and plants suspended in the water drawn to the gills for breathing purposes.

6. The *Ungulata*, because it contains so many grazing animals such as cattle, sheep and goats, which man has domesticated and breeds for their meat and milk.

CHAPTER III

1. I. *Thallophyta:* seaweeds, green algae, fungi, lichens. II. *Bryophyta:* mosses, liverworts. III. *Pteridophyta:* ferns, clubmosses, horsetails. IV. *Spermatophyta: (Phanerogamia):* coniferous trees, cycads, the familiar flowering plants.

2. Bacteria of various kinds (*Bacteria*), Nostoc (*Cyanophyceae*), Euglena (*Flagellata*), Chara (*Characeae*), Fucus (*Phaeophyceae*), Corallina (*Rhodophyceae*), Plasmodiophora (*Myxomycetes*), Mucor (*Phycomycetes*), Penicillium (*Eumycetes*), Iceland Moss (Lichens).

3. The liverworts (*Hepaticae*) are confined to moist situations while the mosses (*Musci*) inhabit a wide range of environments, from walls, tree trunks and dry woodland soil to rocks, moorland places and swamps. Both classes possess characteristic sexual organs, called antheridia and archegonia. It is the absence of sexual organs of this type in the *Thallophyta* which most clearly marks them off from the *Bryophyta*.

4. Class 1. *Lycopodiinae:* the British clubmoss, *Lycopodium* and *Selaginella*.

Class 2. *Equisetaceae:* the common horsetail, *Equisetum*.

Class 3. *Filicinae:* common bracken (*Pteris*), hart's tongue (*Scolopendrium*), polypody (*Polypodium*).

They differ from the *Thallophyta* and the *Bryophyta* in having clearly differentiated roots, stems and leaves. Their internal tissues show a greater variety of structure. They differ from the *Spermatophyta* in having no flowers, and in not producing seeds.

5. In the *Gymnospermae* the female cell

or ovule is not enclosed, so that the pollen grain is brought directly into contact with it. The resulting seed is uncovered. Examples are yew, Scot's pine, juniper. In the *Angiospermae* the female cell or ovule is enclosed in an ovary or seed-case, so that the pollen has to put out a pollen tube which bores its way to the ovule. The resulting seed is covered. Examples are buttercup, dandelion, oak, ash, snowdrop, tulip.

CHAPTER IV

1. The more familiar plants consist of many living units or cells. These are not all alike but have different sizes, shapes and structures, according to the functions they perform. Cells performing the same function are usually grouped together to form a tissue. Thus, there are conducting tissues, like those in vascular bundles; secreting tissues, producing oils, gums, resins, etc.; and protective tissues, like cork and bark.

2. Those tissues whose cells serve as conducting channels for the various food materials throughout the plant are called vascular tissues. They are grouped in distinct strands, the vascular bundles. These are stringy and hard, and often persist as an interlacing skeleton after the death of the softer tissues. They are built up from cells which are considerably longer than they are broad. Some of these cells undergo considerable chemical changes in their cell walls, which result in the death of the cells. These form the wood or xylem.

Other cells retain their cellulose cell walls and living contents, and they form the bast or phloem. The vascular bundles are pipelines for the conveyance to and from every part of the plant of the sap which contains in solution the nourishing ingredients necessary for the well-being of the living cells. The vascular bundles also provide the main supporting skeleton of the plant.

3. The chief work of the leaves is concerned with transpiration, the loss of water as water vapour from the plant, and with assimilation, the uniting together of the simple chemical materials, carbon dioxide and water, to form complicated chemical materials like sugar and starch. Both these are carried out through the agency of the stomata or leaf-pores. The guard cells of the stomata are the only cells of the epidermis which possess chlorophyll-containing plastids.

In the light, they carry out assimilation, thus increasing the strength of their cell sap. This leads to water being absorbed from surrounding cells. The two guard cells swell and move apart, thus opening the pore of the stoma. In the dark, assimilation ceases, the strength of their cell sap falls off, water is withdrawn, and the two guard cells close up together to shut the pore of the stoma.

4. The root and its branches anchor the plant securely in the soil. Only the youngest parts of the root and its branches and the root-hairs which they bear along part of their length are able to absorb water and mineral salts from the soil. The root may swell considerably and serve as a store of food, as in the carrot and turnip.

5. Potassium nitrate, calcium sulphate, magnesium sulphate, calcium phosphate, sodium chloride, sulphate of iron.

6. Water is lost by evaporation from the leaf to the atmosphere. This is facilitated by the opening of the stomata in the hours of daylight. The water so lost is made good by water forced up the stems to the leaves by root pressure. Root pressure is set up as the result of the continuous absorption of water and mineral salts by the root hairs.

Respiration is carried on by all parts of the plant at all times, that is, during the hours of daylight and of darkness. In the daylight, however, it is masked by the process of assimilation, which is only in progress then.

CHAPTER V

1. Because it is the easiest way. Animals do not have to move far to obtain grass, etc., and the plants rapidly replace the parts eaten away, thus providing a virtually inexhaustible supply of food.

2. Because their food—other animals—can run away.

3. Some run their prey down, like the wolves, which hunt in packs and rely on the teeth of the whole pack to hold their victim. Others, like the cheetahs and cats, stalk their prey and then make a final leap. Claws are used to hold down the struggling prey. Fish feeders, like seals and sea-lions, have

sharply pointed teeth for holding on to the slippery prey; so have fish which feed on other fish. Some fish remain immobile until their prey comes within easy reach of the large mouth: examples are pike and the John Dory.

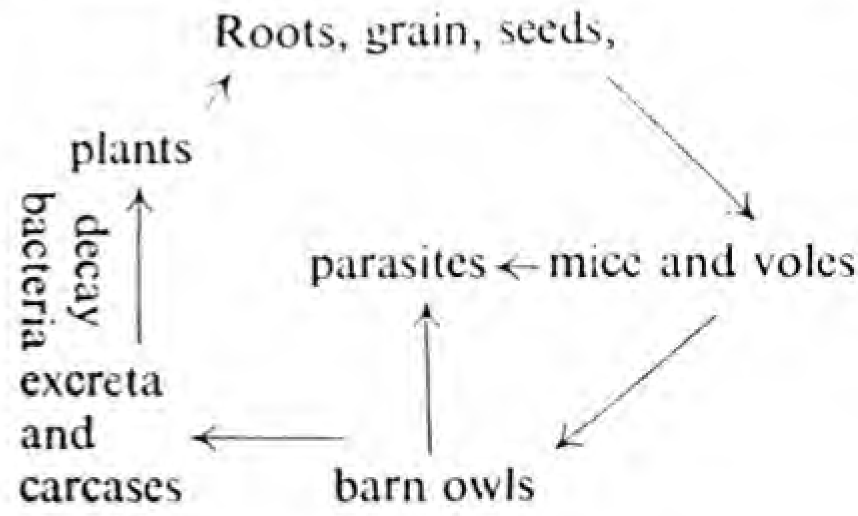
4. Snails are herbivorous, rasping off portions of the plants over which they crawl. Squids and octopuses are carnivorous, seizing the prey by the long tentacles and biting it into pieces by powerful jaws. The bivalves are filter-feeders, filtering the tiny animals and plants which abound in the water. Other filter-feeders are sponges, fairy shrimps, sea-squirts and some whales.

5. Many animals chew up the food into smaller particles before swallowing it. For this purpose mammals possess molar teeth; snails have a file-like radula; insects, *Crustacea* and Arachnids have mandibles; sea-urchins have five teeth. In crabs and lobsters the food is further reduced in size by the gastric mill. In birds the food is swallowed whole or in large pieces torn off by the beak, and in the gizzard it is ground to pulp.

6. Because the food varies. When the diet is exclusively vegetarian we find molar teeth with grinding ridges, as in elephants, rodents, cattle and horses. When the food is flesh, we find molar teeth with strong, broad surfaces for pulping the stringy meat and for crushing bones. When the food is a mixture of these two, as in omnivorous forms like man and pigs, we find the molar teeth fall roughly half-way between these two extremes. Fish eaters have sharply pointed teeth for holding on to their slippery prey.

7. They may be especially developed for boring through hard material like wood, as in weevils and the death-watch beetle; or for sucking up fluids, as in mosquitoes, butterflies and fleas; or for both licking and biting, as in bees and wasps.

8. Herbivorous animals feed on plants. Carnivorous animals feed on the herbivorous ones. Eventually the carnivorous animals die and their carcases rot and decay to release materials which are valuable foodstuffs for plants. Thus the cycle, or food chain, is completed. One example of a food chain is:—



CHAPTER VI

1. Mussels are filter-feeders and so do not move rapidly through the water in search of prey: their food consists of minute animals and plants suspended in the water, and these are filtered off. Slow movements are performed by a digging foot, which is used to anchor the mussel, and the foot also spins additional threads which help to secure the animal in rough water. Octopuses are carnivores, feeding on fish and other living, moving prey. They swim actively through the water by a form of jet propulsion, and search out their prey. They are aided in this search by the huge paired eyes with hard, crystalline lenses.

2. The fore limb (or arm) is modified as a wing, with feathers, which are modified scales, to increase the surface area presented to the air. The muscles operating the wings are so tremendously developed, that the breast-bone is correspondingly developed for their attachment. Some flying animals (other than insects) are flying frogs, the flying snakes and lizards, the cobego, the phalangers and the flying squirrels. These plane or glide: they do not fly in the real sense of the word.

3. The sense of sight, for it is probably used more than any other sense to investigate and take stock of the surrounding world.

4. Some eyes are carried at the tips of tentacles, example garden snail; some at the bases of tentacles, examples limpet and common pond snail; some eyes are great in number and scattered along the edge of the general body covering, example scallop; some eyes are carried at the tops of stalks, examples some crabs and deep-sea fishes.

The eyes of grazing animals occupy more

lateral positions than they do in man because they are always expecting an attack from behind, and, with the eyes in this position, a backward glance is possible without moving the head.

5. The innermost part of the ear in vertebrates is concerned, not with hearing, but with balance. Tiny particles of lime lie bathed in fluid and act in very much the same sort of way as a spirit-level. By this means the animal is informed of its position relative to the vertical and horizontal planes, etc.

6. Taste-buds are special surfaces on tongue and palate for appreciating the taste of things placed in the mouth (or smelled through the nose). In addition, the tongue is used to roll the food into a ball or bolus, preparatory to swallowing. Cats, rabbits and horses wash themselves with their tongues. The lemur's tongue is fringed and is used to comb the animal's hair. The ant-eater's tongue is covered with mucus and is used as a flypaper to pick up termites. The flamingo's tongue is enormous and is used to sieve the bird's food from mud or water. The chameleon's tongue exceeds in length the animal's body, and is used to catch insects, which adhere to it because it is so sticky with mucus.

7. Daylight, fresh air, elbow-room, a suitable soil, i.e., one containing sufficient moisture, mineral salts and other substances for absorption by the roots.

8. The type of plants growing in a certain situation will depend very much on the type of soil. Thus, on the downlands where there are only a few inches of soil covering the chalk, the flora consists primarily of dwarf plants and short turf. On a deep clay soil, on the other hand, we find deep-rooted trees like oak, ash and elm. The seashore and sand dunes have their characteristic plants.

9. Plants of low stature are easily overshadowed by their taller and stouter neighbours. If they are to survive, they must flower and produce seed before their neighbours. This is well seen in woodland flowers like dog's mercury and lesser celandine, which have completed their flowering by the time the leaves of the trees burst out.

10. In cactiform plants the green tissue is situated in the cortex of the stem, and the leaves are greatly reduced in size; they may be found only as scales or hairs or thorns. The stem tissues are greatly swollen with water-storage tissue.

11. The chief problems for plants living in dense tropical forests are to reach the daylight and to secure sufficient living space and fresh air.

CHAPTER VII

1. Predatory animals, like wolves in Northern Europe and stoats in Great Britain, form packs for hunting. In a pack they are able to run down their prey better than when they hunt individually.

Many animals, like buffaloes and lemmings, mass into herds which set off on migrations in search of food (grass, plants). Large numbers give greater security, thus encouraging survival.

2. The polar bear, and, after that, the grizzly bear.

3. Nearly all the weasels have well-developed musk glands, which produce a distinctive odour. Hence the name "foumart" (foul marten) for the polecat. The pine and beech martens, however, do not possess these scent glands and so are called "sweetmarts" (sweet martens).

4. The sloth bear of India.

5. Spreading hoofs prevent sinking in the snow and help in swimming in lakes and rivers. These hoofs click at every step, so that when migrating in darkness or snowstorms, the members of a herd are kept together. The hairs on the body are hollow and filled with air, so that the animal is buoyed up in the water and is thus enabled to swim great distances.

6. In true hibernation the animal builds up a store of fat in its own body to see it safely through the winter sleep. This extends over the whole winter and is marked by the almost complete cessation of respiration, inaction of the digestive organs and the dwindling of the heart-beat to a mere flicker. Examples are hedgehog and dormouse.

In the case of other animals, like squirrels and mice, there is no marked storage of fat within the animals' bodies. Instead, a

store of food is set aside near the hibernation refuge. If awakened, as on unusually warm days in mid-winter, the animals feed from the store, take exercise and explore their surroundings, and only return to sleep when bad weather returns. During this sleep there are none of the accompanying features of reduced respiration and heart-beat.

7. The migration away from the Arctic during the northern winter is necessary in view of the freezing up of the sea then, so that the terns can no longer fish. Instead of migrating to warm equatorial and near-equatorial waters, the terns fly on to the Antarctic, possibly because they are seeking the continuous sunshine experienced during the summer there, and probably because they shun warmth.

8. Usually the cock bird is the more brightly plumaged and either he assists the hen bird in the hatching of the eggs or he leaves this entirely to her. In the case of the red-necked phalarope and dotterel, however, the female is the larger and more brightly plumaged bird, and the male hatches the eggs entirely on his own.

Courtship in birds may be restricted to the relatively short period prior to the breeding season, or it may last for two years before the first eggs are laid, as in the case of the fulmar petrel. The courtship of the golden eagle may extend over years. This courtship is marked by clever aerial acrobatics. A common feature of many bird courtships is song.

CHAPTER VIII

1. It provides a stiffening, supporting framework for the soft parts of the body. Without it the body would collapse into a shapeless heap. It provides attachments for the muscles of the body, which operate the limbs as a system of levers. It provides protection for vulnerable and delicate organs, e.g. the skull protects the brain. In the marrow of hollow bones, new red and white blood corpuscles are manufactured in large numbers.

2. Gristle forms the greater part of the skeleton of the young child and quite a large part of the skeleton of the growing adolescent. As the years pass, more and more of it is replaced by bone until, when growth ceases, replacement is complete. In the skull some bones are first represented by sheets of membrane, not cartilage.

3. All living cells in the body are supplied with food and oxygen by the blood, which reaches them via the capillaries, which are of extremely small size. Their walls, too, are very thin, so that the oxygen, carried along in the blood in the red blood corpuscles, easily passes through to the living cells which require oxygen, and the food, dissolved in the blood plasma as protein or blood-sugar, readily leaks out with the lymph which bathes all living cells.

4. The functions of the blood are: (1) to convey oxygen from lungs to tissues in red blood corpuscles; (2) to convey carbon dioxide from tissues to lungs in blood plasma; (3) to fight off attacks of harmful germs by white blood corpuscles; (4) to clot and so stop up a wound; (5) to collect nitrogen-containing waste materials from the tissues and convey them to the excretory organs (kidneys); (6) to convey hormones from the glands (e.g. thyroid gland), to all parts of the body.

Blood freshly charged with oxygen passes from the lungs to the left auricle. Blood lacking in oxygen fills the right auricle, coming from all parts of the body except the lungs. Both auricles contract together, filling the two ventricles. The two ventricles contract together. The right ventricle sends its blood to the lungs to receive a fresh charge of oxygen, and the left ventricle sends its blood all around the body. Arteries convey blood away from the heart, while veins convey blood towards the heart.

5. Before the food can be used by the body it has to be broken down into materials which are capable of being absorbed into the blood. Complicated proteins are broken down by digestive substances into simpler proteins and eventually into amino acids. Starches and complicated sugars are broken down into simpler sugars, such as grape sugar. Fats are broken down into glycerine and fatty acid. When these chemical changes have been carried out, the resulting materials dissolve in the blood plasma and are conveyed in it in solution to all parts of the body, and, where they are

needed, they are absorbed directly from the blood plasma.

6. Where there is no great urgency for speed of action, integration is often carried out by hormones or chemical messengers. These are poured out into the blood stream by glands, like the thyroid gland and the pancreas, and these secretions travel to all parts of the body, causing changes in some tissues and organs, but not in others, i.e., some are affected and some are not. Where there is an urgent need for speed of action, integration is effected through the nervous system.

CHAPTER IX

1. His ability to make fire, to read, to write, to speak and to laugh. His mind can foresee future needs, so that he plans for the future and lays in stores of grain, etc. He has an intellectual, moral and religious life quite unknown in other animals.

2. The first is a general mental ability which is inherited, called "g." The second is a specific mental ability, and is largely acquired in the lifetime of the individual. An intelligent person quickly sees to the heart of a problem and his solution of the situation is prompt and correct. The less intelligent person cannot see his way out of the situation at all clearly, and has to have a number of attempts at it.

3. McDougall's definition of an instinct is "an inherited disposition (1) to pay attention to objects of a certain class; (2) to feel in relation to the object a feeling of a particular quality; and (3) to act in a particular way in regard to the object, or, at least, to feel an impulse to such action."

Examples of instinctive behaviour are the movement of salmon upstream to spawn; the migration of eels to the West Indies to spawn; the human baby at a very early age grasps a stick held before it and hangs therefrom; the newly hatched cuckoo pushes out the other eggs from the nest. There are, of course, many other examples.

4. The restless and destructive energy of the young hooligan can be redirected under the influence of an ideal, e.g., he may become a member of a football team or a dependable member of a Scout patrol.

The sex impulse can be expressed in creative work for the good of the community, e.g., organizing and running a youth club.

5. The tests seek to show the quickness and accuracy with which the person being examined sees the relationships in a situation. For instance, the question may ask for the blank spaces to be filled in for sentences like "as foot is to shoe, hand is to——" (glove), or "as black is to white, cold is to ——" (heat, warmth).

6. Flight (fear); pugnacity; repulsion (disgust); parental instinct; appeal; sex; curiosity; submission; assertion and self-display; gregariousness; food seeking; acquisition; construction; laughter.

CHAPTER X

1. The simplest method of reproduction is by fission or splitting into two. When the two products of this fission reach the normal adult size, they, too, split into two. Examples are provided by unicellular animals, like amoeba. Some simple animals, like hydra, reproduce by budding, the bud separating from the parent after growth has proceeded a certain way. Hydra may also reproduce sexually. Some animals, like sponges, planarian worms and starfishes, can regenerate lost parts. This is an artificial form of reproduction, resulting only from accidents.

2. In higher animals, only sexual reproduction is practised. In higher plants, asexual or vegetative reproduction may be going on alongside sexual reproduction.

3. Regeneration refers to the regeneration of lost parts. In the case of higher animals, such as man, this regeneration is confined to the healing of wounds and of the stumps of limbs. In lower animals, like starfishes and planarian worms, a severed tail may grow a new head, and vice versa, thus providing another form of reproduction.

4. A hermaphrodite animal contains both male and female organs (gonads) in the same body, e.g., earthworm, snail.

Parthenogenesis or virgin birth means that eggs develop successfully without the aid or intervention of a male. Examples are greenfly (*Aphis*) and honey bee. In the latter, fertilized eggs develop into workers

or queens (females), while unfertilized eggs develop into drones (males).

5. The young corncrake has numerous enemies, including man with his agricultural implements, such as tractors. The siting of the nest in cornfields lays the young open to obvious risks. The fulmar petrel is reared on inaccessible ledges, and has few enemies.

6. The birds which lay eggs which harmonize closely with their surroundings do not usually construct a real nest, but merely scrape out a hollow on the ground, e.g., oyster-catcher. Birds with conspicuous eggs usually construct nests or hide them in hollows or tunnels, e.g., starling, owl, kingfisher.

7. In higher animals the sexes are separate, that is, there is a male, bearing male gonads, the testes, and a female, bearing female gonads, the ovaries. The cells produced by the ovaries are the eggs or ova, and these cannot undergo development into new individuals until they have been fertilized by the spermatozoa, which are the cells produced by the testes.

In creatures like the frog we find the eggs are fertilized by the spermatozoa outside the body of the female. In reptiles and birds we find the eggs are fertilized inside the body of the female, and then are laid with shells around them. In mammals the eggs are fertilized inside the body of the female, and there they undergo their development, later being born as young animals in an advanced state of development.

CHAPTER XI

1. By vegetative or asexual methods which involve no sexual processes. In unicellular plants, like bacteria and blue-green algae, this is accomplished by simple division of one cell into two. In filamentous algae like *Spirogyra*, the individual cells in a filament may separate and each grow into a new filament. In flowering plants portions of the plant may become separated from the parent by the decay of connecting pieces, e.g., strawberry runners, rose suckers. Gardeners exploit this asexual propagation when they take "cuttings" of plants.

2. The asexual method of reproduction described above for *Spirogyra* is not usual. The usual method is sexual. Cells of adjacent filaments form connecting bridges and through these the cytoplasmic contents of the cells of one filament pass over to fuse with those in the other filament.

3. In true sexual reproduction the formation of a new individual occurs only after two distinct cells, one female, the other male, have fused together and their two nuclei have united together, forming a fertilized egg or zygote.

4. There are two phases in the life-cycle which alternate in regular succession—the sporophyte generation, producing spores, each of which on germination grows into a gametophyte. This bears sexual organs, producing male and female sex cells or gametes. Union of one male and one female gamete produces a fertilized egg or zygote, which grows into a new sporophyte.

5. They lack the (usually) conspicuous flowers of the flowering plant, and do not produce fruits and seeds.

6. Inconspicuous flowers are possessed by plants in which cross-pollination is brought about by the wind, as in hazel, dog's mercury and grasses. Conspicuous, brightly coloured flowers are possessed by plants relying on insects for cross-pollination, as in monk's-hood, pea and violet.

7. The fruit is all that part of a flower which persists after fertilization until the seeds are ripe, and as there are such wide variations in floral structure, there are correspondingly wide variations in fruit structure. All the various forms of fruit are devices for ensuring the satisfactory dispersal of seeds.

CHAPTER XII

1. (i) Modifications, which result from the response of the individual organism to external influences (nurture).
   (ii) Inborn or innate hereditary characters, which result from the fact that the individual organism is the progeny of its parents (nature).

2. Because each contributes the same number of chromosomes, and, further, the union of spermatozoon and egg unites members of pairs of chromosomes. The

large numbers of hereditary elements, the genes, are resident in the chromosomes, and the members of a pair of chromosomes carry the same genes arranged in the same order.

3. The mass of cells which constitutes the organism is derived from the fertilized egg by cell division. At each such division each chromosome in a pair of chromosomes divides into two after the genes have undergone a doubling. The daughter chromosomes separate in pairs, a pair going into each daughter cell (mitosis).

4. That, being proteins, genes are enzymes, too. Each of these different enzymes, produced by the different genes, has its own particular effect on the growth and development of the organism.

5. When a gene undergoes a change in its own internal organization, it becomes a mutant gene. It still affects the same growth and developmental processes as did the original gene, but in a different way and in a differing degree. Thus, there results a change in the character of the developing organism, which is described as a mutation.

6. When the germ cells, spermatozoa and eggs, are formed, the cells dividing to give rise to them undergo, at one stage, a reduction division or meiosis. At this division the two members of each pair of chromosomes are separated, so that each spermatozoon or egg contains only one member of each pair of chromosomes. Thus, the number of chromosomes in each egg and spermatozoon is reduced to half the normal number for the species. Union between the two to give a fertilized egg restores the normal number for the species. If meiosis did not occur during the formation of the sex cells, the number of chromosomes would be doubled at each fertilization.

7. Mendel's first law states that the sex cells, spermatozoa and eggs, contain only one of any pair of factors (alleles), present as a pair in the ordinary body cells of the organism. This law still holds true, as we should expect in the light of our knowledge of meiosis.

Mendel's second law states that the segregation of factors (alleles) described in the first law as taking place in the formation of sex cells, takes place independently and at random, that is, the distribution of the members of one gene pair between the sex cells is influenced in no way by that of any of the other genes present. It is now known that this law holds only when the genes under consideration reside in different chromosomes. If they should reside in the two members of a pair of corresponding chromosomes, then crossing-over disturbs the law.

8. One sex, more commonly the female, is homozygous for the genes of sex. These genes are located in a pair of chromosomes, called the X chromosomes. The ordinary body cells of such a female are XX so far as the sex chromosomes are concerned, while her eggs each contain only a single X chromosome, by segregation.

The male is heterozygous for the sex genes. The ordinary cells of his body are XY, that is, each contains one normal X chromosome and one Y chromosome. The latter is unlike the X in respect of the genes it contains. Part of it is homologous to the X, the rest is not. By segregation, half the spermatozoa of such a male contains one X chromosome; the other half, one Y chromosome.

When an X sperm fertilizes an egg (X), the result is a female (XX). When a Y sperm fertilizes an egg (X), the result is a male (XY). In some animals the relationships are reversed, that is, the male is XX and the female XY.

CHAPTER XIII

1. Lower organisms, like the oyster and the ling, produce very great numbers of very small eggs, which are practically devoid of yolk. Development is rapid and takes place after the eggs have been shed freely into the water. Here many enemies, tides, currents, etc., destroy the greater part of the progeny, but so many were released, some must survive by pure mathematical chance.

Higher organisms leave nothing to chance, but produce small numbers of large eggs, which contain a great store of yolk; examples, lizards and birds: or they produce a small number of small eggs, which contain very little yolk, but these are retained within the body of the female parent

until fully developed. Examples: mouse, monkey, man (mammals).

2. Because it becomes sexually mature and can reproduce while still in the larval (tadpole) condition. If it is not given extract of thyroid gland, it never really grows up.

3. The shell of the egg is a protective barrier, within which the embryo can develop without much fear of attack by other animals. The membranes and fluids contained in the egg absorb any bumps and shocks to which the egg may be subjected, thus screening the developing embryo. The store of yolk is an ample supply of food for the embryo, which is thus able to spend some time over development, hatching out eventually as a completed young individual.

4. The young learn from their parents by example. They also gain the protection of the larger and more experienced parents when danger threatens. Child welfare in nature depends largely upon the number in the family.

5. The marmoset, Australian brush-turkeys, the North American bow-fin, the three-spined stickleback, the fighting fish of Siam, the paradise fish of China, and the small South American frog, which carries the eggs in an enlargement of its vocal sac.

6. Because the eggs have so many natural enemies that none would survive unless tremendous numbers were laid. Instead, a moderate number is produced and looked after by one or both parents.

7. The legs would not be able to carry the weight of the body. If so large a body is to be carried, the legs would have to be proportionately so much larger and stronger; that is, the giant would no longer be of human proportions.

8. Because they take longer to reach their adult size, and most animals do not become sexually mature until this adult size is reached.

CHAPTER XIV

1. Firstly, that there is a struggle for existence; secondly, that animals vary; thirdly, that, as a result of these two, natural selection takes place.

2. (i) Adaptations to a life in water are shown by fishes, *ichthyosaurs*, turtles, dolphins, seals and whales. Fishes are close to the ancestral vertebrate stock; *ichthyosaurs* and turtles are reptiles; dolphins, seals and whales are mammals.

(ii) Adaptations for making great jumps or leaps are shown by grasshoppers, fleas, frogs and kangaroos. Grasshoppers and fleas are insects; frogs and kangaroos are vertebrates—frog, an amphibian; kangaroo, a mammal.

(iii) Adaptations for life in the air are shown by butterflies, moths, flies, *pterodactyls*, eagles, flying squirrels and bats. Butterflies, moths and flies are insects; *pterodactyls* were reptiles; eagles are birds; flying squirrels and bats are mammals.

3. The wombat parallels the bigger rodents; the Tasmanian cat, the true cats; the Tasmanian wolf, the true wolf; the kangaroo, deer and other herbivores which are fleet of foot.

4. He was able to offer a reasonable explanation of the peculiar features in the geographical distribution of animals. The longer an island has been isolated, the greater is the number of species and varieties peculiar to it. The strange and widely diverse marsupial fauna of Australasia is explained in terms of geological separation and geographical isolation.

5. That male animals compete for the females. Males with greater strength, better weapons or more striking adornments would be more successful. As the competition increases between males, the ornaments or weapons might be developed to such a degree as to become detrimental to the animal except when courting the female.

6. According to Lamarck, the giraffe's neck has become progressively longer as the result of successive generations of giraffes reaching up to browse on higher and still higher foliage. This assumes that the increase in length of neck gained in one generation is inherited by the next, which thus starts with an initial advantage.

According to Darwin, the lengths of giraffes' necks have varied. Those with longer necks have had a distinct advantage over those with shorter ones, being able to reach foliage denied to the others. In this competition for food, nature has selected

out those with longer necks, which has led to the exclusion of the shorter necked ones. Natural selection acting in this way over long periods of time, on widely varying lengths of neck, has perpetuated those with the longest necks.

7. Only animals with hard parts which were buried in mud, silt or dust are at all common as fossils. Thus, we know a good deal about the fossil history of vertebrates, but practically nothing about the evolution of the worms.

In the earliest rocks we find the remains of animals well advanced in their evolutionary history. The sedimentary rocks containing the earlier parts of their history have been lost.

The fossil record very rarely produces a truly intermediate form.

8. Firstly, mutations are relatively rare —the rate of mutation varies, but is always extremely slow; secondly, mutations are trivial—they control only small details of colour-pattern or small anatomical differences in not very essential organs; thirdly, mutations so frequently have a bad effect on the organism.

CHAPTER XV

1. It is the study of living animals and plants in relation to their environment.

2. About twenty thousand, and about half a million.

3. Up to 100,000 or even more per litre (a litre is nearly 2 pints).

4. Birth-rate, death-rate, and length of life.

5. Anything which affects birth-rate, death-rate and length of life; e.g., temperature, rainfall and the weather conditions, food supply, economics, parasites and disease.

6. When out of all the eggs or young that are produced by one pair of animals in one generation, two, and only two, survive to maturity to produce young in the next generation.

7. It is a rodent that lives in Northern Europe. Every few years it increases enormously in numbers and overflows in thousands from the hills to the plains of southern Scandinavia.

8. It is the study of the sequence of seasonal events during the year, and their relation to weather conditions.

CHAPTER XVI

1. Antibodies are manufactured in the lymph glands and circulate round the body in the blood plasma. They are proteins and may be divided into four main classes, as follows : (i) antitoxins, which neutralize the toxins or poisonous materials produced by bacteria which invade the body : (ii) agglutinins, which cause bacteria and other foreign bodies to agglutinate or stick together in clumps; (iii) lysins, which cause bacteria and other foreign bodies to disintegrate; (iv) precipitins, which precipitate colloidal substances.

2. By " immunity " is meant the resistance of the host to infection by bacteria. This immunity may be (a) inborn or congenital, or (b) acquired, and acquired immunity may be brought about in two ways:—

(i) naturally acquired immunity—by the host actually contracting the disease, so that the experience stands him in good stead and it is most unlikely that he will get the disease a second time;

(ii) artificially acquired immunity—by the host learning how to deal with the disease by being artificially injected with either "toned-down" toxins, as in the case of diphtheria, or with dead bacteria, as in the case of typhoid.

3. In the disposal of sewage, use is made of the fact that the bacteria of decay break down organic materials into simple substances, which are used as manures. The bacteria in the alimentary canal of man manufacture vitamins in the B group, which are absorbed by the host.

Many industrial processes are carried out with the aid of bacteria, for example, the manufacture of vinegar and acetone, and the making of cheeses.

4. One may become infected by one of the excremental diseases, that is, one of the diseases where the excreta of an infected person contain the bacteria causing the disease, and these bacteria are washed away into the soil, stream or well. Typhoid is

commonly spread in this way in countries with poor sanitary arrangements.

5. (i) The macrophages seize any foreign bodies floating in the blood stream and destroy them. They are thus an important factor in combating disease.
   (ii) They behave as general scavengers and remove dead or unwanted tissue.
   (iii) Those in the spleen remove and break down worn-out red blood corpuscles.
   (iv) Those in the liver remove vitamins in the blood and pass them on to the liver for storage.
   (v) Those in the bone marrow remove iron from the blood and pass it on to the cells making new red blood corpuscles.

CHAPTER XVII

1. The chief enemies of domestic animals are (i) wild animals; (ii) adverse weather, such as extreme cold; (iii) shortage of food at certain times of the year. They can be protected against wild animals by keeping them together in herds, by enclosing them with a fence or wall, especially at night, or even by shutting them off in a stable or shed. They can be protected against the weather by bringing them to more sheltered and warmer places at certain seasons (e.g., ewes at lambing season) and into sheds and stables. They can be prevented from starving when there is a seasonal shortage of food by having carefully stored reserves of food put aside for such an eventuality.

2. By spraying with substances poisonous to insects, like derris, pyrethrum, nicotine, D.D.T. and Gammexane, or by introducing a natural enemy of the insect pest; for example, ladybirds were introduced to deal with scale insect on oranges and lemons in California.

3. The destruction of trees leaves the soil open to erosion by rain, while the destruction of trees on a very large scale (the removal of complete forests) may decrease the rainfall. Forest belts encourage the precipitation of rain and act as windbreaks for crops.

4. The production of a specialized animal or plant often entails inbreeding, and inbreeding often leads to a marked susceptibility to disease. For example, cows bred for high milk-production succumb more easily to bovine tuberculosis, and hens bred for egg-laying are not very successful at brooding and bringing up families of chickens.

5. Because the natural enemies of the rabbits were absent in Australia, and so they multiplied without any restraining influences.

6. (i) By introducing laws—game laws—limiting or prohibiting the destruction of certain animals (and plants).
   (ii) By setting aside large areas of land as national parks and game preserves, in which no one is allowed to interfere with the wild life in any way.
   (iii) By the creation on a smaller scale of bird sanctuaries and zoological gardens.

7. (i) By the extended use of fish hatcheries, where eggs are artificially fertilized, and the young fish reared in this way are not put into the river, lake or sea until growth has proceeded some way and the young fish are, in consequence, better able to fend for themselves.
   (ii) By prohibiting the use of fishing nets with too small a mesh, so that only the larger fish are caught.
   (iii) By prohibiting the excessive fishing of any one aquatic animal, for example, whales.
   (iv) By extending our knowledge of the interdependence of larger fish on smaller fish, and of these in turn on microscopic organisms (plankton).

8. Man's interference with nature has always had a beneficial effect for man himself, but often this effect has been of very short duration. Often complete disaster has followed. For lasting and continued benefit, man should respect nature and interfere with natural processes as little as possible.

INDEX

Numbers in italics indicate illustrations

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